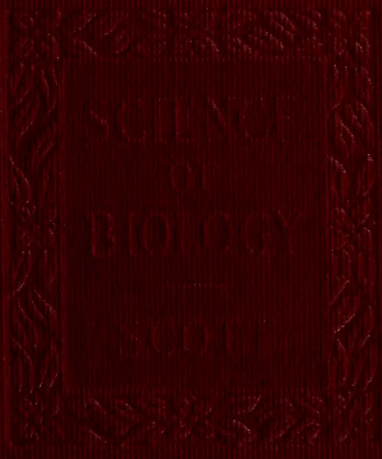
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THE SCIENCE OF BIOLOGY

"The blue sky, the brown soil beneath, the grass, the trees, the animals, the wind, and rain, and stars are never strange to me; for I am in and of and am one with them; and my flesh and the soil are one, and the heat in my blood and in the sunshine are one, and the winds and the tempests and my passions are one."

—W. H. Hudson, in "Hampshire Days."

THE SCIENCE OF BIOLOGY

An Introductory Study

BY

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NEW YORK

THOMAS Y. CROWELL COMPANY

PUBLISHERS

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Second Printing

Printed in the United States of America

PREFACE

Any comprehensive survey of Biology must include a study of Plant life as well as of Animal life. If there is anything valid in the idea of evolution, it is patent that these two great groups of living organisms evolved during the ages alongside each other.

In this book an endeavor has been made to give a brief but systematic presentation of both forms. It is confusing, however, to try to study them in concert. Instead the author has chosen to make a study of the entire series of Plant types, followed by a similar study of Animal forms.

Principles are introduced as groups are taken up, and then reiterated as they appear in the study of higher groups. The author considers that a presentation of principles, without the background of types and groups, is not an effective method. With the fundamental grounding in systematic relationships the student can " place " the forms which illustrate a certain principle, basing his application on what he has learned in the classroom and laboratory.

The book is divided into four parts. Part I is introductory and contains an account of the various biological sciences, also a general study of protoplasm and the cell. Part II considers the biolcgy of Plants, and Part III, that of animals. In these parts the questions of behavior, parasitism and economic biology are included, wherever they are pertinent to the group under discussion. Part IV deals with general topics such as Comparative Anatomy, Histology, Embryology, Heredity, and Evolution. Here a choice must be made of treating either plants or animals from a comparative point of view. Although all living things have resemblances in common, yet as evolution proceeded, the whole organization of both forms became more widely separated and specialization was achieved along two extremely different roads.

Confronted with the necessity of making a choice, it

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was decided to give more consideration to the Animal World and especially the Vertebrates, because the resemblances are well defined and because there is a special human interest in studying the group to which man himself belongs. References are also made to special types of plants and lower animals, wherever it is reasonable to do so. The last chapter deals with the Biology of Man, and where this study ends, the psychologist and the sociologist can treat further of the supra-biological phenomena of human individuality and society.

In the preparation of this book, the author has had the assistance of many minds. Due honor is paid to the host of early makers of biological science. Particular attention is called to the selected references at the end of each chapter. The author wishes to thank especially the American Museum of Natural History, the U. S. Bureau of Fisheries, the U. S. Department of Agriculture, the New York Zoological Park, The Macmillan Co., Henry Holt and Co., the McGraw-Hill Book Co., the W. B. Saunders Co., D. Appleton and Co., E. W. Sinnott, and others for the use of photographs or other material. He is indebted to Joseph Rubinger, Malcolm Dodson, Samuel Sugar, and Janet Spaulding for making many of the drawings, and to Bernard Fread for some of the photographs; also to Maurice Bratter, Herbert Ruckes, and Earl A. Martin for assistance in making the photo-micrographs. He wishes to thank Phebe Ann Scott, Irving Kushner, Max Wiwak, Theo. Niver, Randolph Halsey, Philip M. Jones, Herbert Ruckes, Earl A. Martin, William W. Browne, Robert A. Budington, J. Arthur Dawson, Ernest Scott, and Ivy Lewis, for reviewing manuscript and proof; and to the publishers for their generous support.

The book is dedicated to every student who may find in it some assistance in guiding him to an understanding of the part that Biology should play in the proper ordering of human affairs.

G. G. S.

New York, February, 1925.

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Part I.—INTRODUCTION

THE SCIENCE OF BIOLOGY

CHAPTER I

THE BIOLOGICAL SCIENCES

Biology is the science of living things. It includes not only everything that has to do with the life of lower animals, but also everything that pertains to man and his activities. In this sense it embraces all human knowledge. However it is usually confined to restricted limits. *Botany* is that branch of biology that deals with plants and *Zoology* deals with animals.

Morphology.—There are two points of view from which we may study plants or animals. An engineer would be chiefly interested in the method of construction of a great industrial building, the materials used and how these are put together. In like manner some biologists are interested chiefly in the forms, parts, and structures of plants or animals. This is the science of *Morphology.* The field is so large that it would be practically impossible to be an expert in both *Plant Morphology* and *Animal Morphology.*

Physiology.—In the case of the industrial plant referred to above, some persons would be more interested in what things are going on in the building, what it is used for, the arrangements for taking in the crude materials, the various processes involved in this department and that, and the assembling of the completed product of manufacture. Such a person would be interested in the function of the building. So in biology some students are more interested in the functions of living things, the processes going on, the sum total of which means life. The science of function is *Physiology.*

Morphological Sciences

Anatomy.—Biologists call living things *Organisms*. The word literally means that which is composed of organs. An organ is a part having a particular function. The heart pumps blood and the lungs are concerned in bringing oxygen to the blood. The heart is an organ and the lungs are organs. But not all living things have organs. Some organisms are small and simple yet they are able to perform all the functions that constitute life, without any special organs.

We obtain a knowledge of the morphology of an animal by examining it by means of scalpel, scissors, needles and forceps—i.e., with dissecting instruments. This is a process of analysis. Knowledge of the organs of which a living thing is composed is called *Anatomy*. There is a *Plant Anatomy* as well as an *Animal Anatomy*. To write a book on the anatomy of any animal, one would dissect a great many specimens of a certain kind of animal, make exact drawings of all the different parts and write accurate descriptions of them, including a careful study of the external appearance. The animals would not be identical in structure, but the account would be an average picture of the structure of that kind of animal. If the human body were the object of the investigation, then the completed treatise would be *Human Anatomy*. If the studies concerned the horse, ox, sheep, etc., then one would have written the *Anatomy of Domestic Animals*. If the researches included all kinds of animals, then one would discover many points of resemblance in spite of special differences. This would suggest comparison of structures. Because of kinds of similarities, it would be found that all the forms naturally arranged themselves into a few great groups within which the resemblances were more striking. Thus all fish are in many respects alike, and reptiles are more or less alike. This account of resemblances constitutes *Comparative Anatomy*.

Histology.—Next one might dissect each of the organs and thus find that they are built up of a few different kinds of

materials. They are covered with layers of material called *epithelium*; their movement is due to a material called *muscle;* they are held together by means of *connective material,* while thread-like or cord-like strands convey messages from one to the other. The latter are *nerves.* All such materials are nourished by a material called *blood.* Epithelium, connective, muscle, nerve, blood are tissues and the elementary units in each tissue are very similar. *Histology* is the science of the tissue construction of organs.

Cytology.—Proceed further and cut very thin slices of tissue with a razor. Dissect a small bit of it apart with needles, place this on a thin glass plate called a microscopic slide, and study it under the lens. Treat the material with certain chemical reagents and it will be discovered that each of these tissues is made up of units of varying size, shape and complexity, known as *Cells.* These cells are ultimate life units. The study of cell morphology and physiology is called *Cytology.*

Embryology.—Animals usually begin their lives as a single cell. This divides and subdivides, different kinds of cells result, tissues are laid down, organs appear, until at last the adult animal evolves. The scientific discussion of such phenomena of *development* constitutes the science of *Embryology.*

Pathology.—Organisms become ill, organs or tissues become diseased, and in some cases death occurs. Certain biologists make detailed studies of these diseased tissues or organs, compare them with the normal condition, attempt to explain just what has happened, and strive to find out how this change can be prevented. The study of diseased tissue, its cause and result, is *Pathology.*

Palaeontology.—The earth has existed for thousands of centuries, but life is not as old as the earth. There is evidence that many kinds of animals and plants inhabited the earth in bygone ages and later completely disappeared. After death took place, the skeleton or shell or woody stem petrified, or its form became otherwise preserved and became a " fossil." The study of fossilized remains of the organic life of past ages comprises a considerable part of the science of *Palaeontology.*

Taxonomy.—It is almost an instinctive attribute of the human mind to arrange surrounding objects in some sort of order. The multiplicity of forms of plants and animals presents a rich field for the exercise of this inclination. Thus there has arisen a special science of the classification of plants and animals, known as *Taxonomy.*

Ecology.—Every animal and plant lives in a world of ever-changing conditions. A great part of the job of living consists in an attempt to make successful adjustments to surrounding conditions. A study of the relation of organisms to their environment is called *Ecology.*

Genetics.—A child is said to resemble its father or its mother or ancestors in one respect or another. Such phenomena are true not only of human beings, but of all plants and animals. To-day a great deal is known about such things because they have been carefully studied. This branch of biology is the science of heredity or *Genetics.*

Evolution.—There is a multiplicity of facts to prove that the present-day variety of plant and animal forms has not been present since the beginning of life upon the earth. Some forms are older than others. We can trace their ancestors back to the early forms of life. Others, like flowering plants and dogs and cats, are of more recent origin, than ferns and reptiles. All along the historical pathway of organic life new forms diverged from the then existing lines. Fish appeared before frogs and reptiles originated before birds. Birds had reptilian-like ancestors, and insects had worm-like ancestors. All the evidences make for the theory that there has been a gradual evolving of living forms in the history of life on the earth. From the simple have come the complex. This concept resulting from biological study has resulted in the *Theory of Organic Evolution.* It is a tentative conception which appears to fit the facts discovered more adequately than any other explanation yet advanced.

Geographical Distribution.—The animal life of a region constitutes its *Fauna,* the plant life is the *Flora.* The fauna and flora of a region are quite distinctive. Desert regions have their own peculiar fauna and flora, and tropics

have a type of fauna and flora unlike that of temperate zones. The study of the distribution of organisms in space constitutes the science of *Geographical Distribution.*

Physiological Aspects.—The above sciences are more or less morphological, *i.e.*, they are concerned with forms and structure. Anatomy and histology would seem to be chiefly morphological. Embryology has been so, but, in reality, development is an active living process. It is far easier to describe and compare the structure of a 48-hour and a 72-hour chick embryo, than to explain *how* the latter developed from the former.

The most important things to know about cells are their functional activities. How does a diseased organ function? What is the effect of this on the functioning of the entire organism? These are the physiological aspects of pathology, and by no means the lesser side of it.

The lifeless organisms which the morphologist dissects cannot adapt themselves to external changes. The ecologist studies living forms, and it is after all the physiology of adaptation that constitutes his main interest. One might conclude that palaeontology is all morphology. But the palaeontologist from his remnants of bones and teeth attempts to visualize the living, moving monster of long ago and the living plant world of those far-off days. Moreover Professor Moodie has recently discovered evidences of disease which occurred in certain kinds of prehistoric animals. Even the palaeontologist cannot get away from physiology.

The study of genetics has been to a considerable extent morphological, because it has been concerned chiefly with the structural manifestations of heredity. The essential phenomena are physiological even though at present they may not be understood. Morphology has been the easier path. It is natural to see why man should have first attacked biological problems from this standpoint. The unexplored realms in biology are chiefly physiological.

Special Branches.—In addition to the general sciences named above, there are numerous special branches. Many biologists devote all their time to a study of some special

field. The *Ornithologist* studies birds; the *Ichthyologist*, fishes; the *Entomologist*, insects; the *Herpetologist*, reptiles; the *Protozoologist*, single-celled animals; the *Bacteriologist*, bacteria; the *Algologist*, algae, which are the simplest forms of green plants. The *Neurologist* studies the anatomy, physiology and pathology of the nervous system.

Related Sciences.—There are certain sciences connected with man that are more or less intimately related to biology. Thus *Human Psychology* is the study of the mind; *Comparative Psychology* investigates the mental phenomena of all animals. Mental operations are not possible in lifeless material. In some manner not yet made clear, mental activity and a functioning nervous system are vitally connected. *Anthropology* is a scientific study of man, his origin and physical history, and what he has accomplished. Part of its problem is an explanation of the part played by biological principles in making man what he is. *Sociology* is the study of the problem connected with the endeavor of men to live in more or less close relationship with one another. In these human relationships the basic questions are, after all, connected with the satisfaction of individual physiological needs. Due to geographical barriers, climate, food supply and other more or less accidental phenomena, certain groups of people are forced to become closely interrelated and develop into races of mankind; and the scientific study of such questions which are rooted in biology forms the science of *Ethnology*. One of the products of social organization is property. The so-called science of the whole question of property constitutes *Economics*. These biological organisms called men can readily communicate with each other, and so we have *Language*. Thus, without effort, we can reach out here and gather in there and, plant the flag of biology on the uttermost boundaries of human knowledge!

Usually speaking, biology is restricted to the morphology and physiology of living things. In the wider sense of being applied to any description of life it extends back into the dim ages of antiquity. In the narrower, more scientific sense it is very modern. The word was first used in the

early part of the nineteenth century. In fact, it was not until 1861 that sufficient exact knowledge had accumulated to warrant the notion of a general science of Biology.

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CHAPTER II

PROTOPLASM—THE PHYSICAL BASIS OF LIFE

All living organisms agree in at least two respects. In the first place, they consist of a special organization of certain chemical elements called *Protoplasm*, and second, this substance occurs in units called *Cells*. What is protoplasm? Let us examine it first from a physical standpoint.

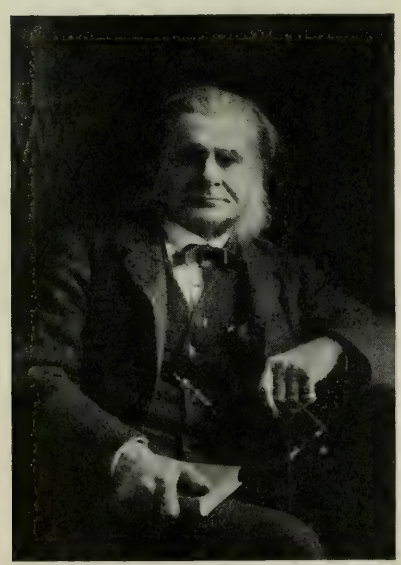


Fig. 1.—T. H. Huxley (1825–1895)

Physical Characteristics.—An eminent English scientist, T. H. Huxley (Fig. 1), delivered an epoch-making address in Edinburgh in 1868 entitled the "Physical Basis of Life," his name for protoplasm. Crush a few plant or animal cells, and examine the material under a microscope. This living material appears to be translucent, and nearly colorless. It may look like jelly with little dot-like granules in it. It is sticky, cohesive; it flows like thick mucilage, is viscid; there appear to be little round spaces in it, it is vacuolated; it refracts light. It is heavier than water. It appears to be watery. Material from one source (*a*) may appear to be a mass of network of fine threads imbedded in a jelly-like groundwork; (*b*) from another source, the network may appear to be coarser threads also imbedded in a thin,

watery jelly; or (*c*) as granules in jelly, or (*d*) little bubbles of different sizes enmeshed in a jelly-like groundwork.

These descriptions roughly suggest four different theories as to the physical appearance of protoplasm: (*a*) *Reticular;* (*b*) *Fibrillar;* (*c*) *Granular;* (*d*) *Alveolar.* All these descriptions substantiate the fact that protoplasm consists of a more solid substance (granules; fibers, etc.) the *spongioplasm* imbedded in a clear liquid substance called *hyaloplasm.* Formerly some biologists were quite concerned as to which of these was the real living substance. There is no evidence that life is possible without both of these substances.

Chemical Characteristics.—Chemical analysis has shown the presence of a great many compounds which are probably always present in protoplasm. There are a number of classes of these such as (1) *Water,* (2) *Salts,* (3) *Gases,* (4) *Proteins,* (5) *Carbohydrates,* and (6) *Fats.* Let us consider these.

(1) *Water.* Protoplasm is not soluble in water, and yet there is always a great deal of water in it. It might be more correct to say that it is dispersed in an aqueous medium. Protoplasm contains on the average about 60 per cent of water; muscle contains even more, about 75 per cent; bone less, 25 per cent; jelly fishes are almost all water. They have been called living sea water. Water is indispensable to life, which is a series of chemical transformations. Water is the medium in which these changes take place. Dehydration or loss of water usually causes death. Some organisms are more resistant to loss of water than others. The summers in California are seasons of drought. The fields are covered with dead grass. Uncultivated plants show very little green growth. Those that are green obtain a water supply by sending roots far beneath the earth where water still remains. Irrigation, however, makes plant life possible in profusion. Even in the Eastern states, although there could not be much growth in the cold season, yet the cessation of the free movement of water in plant bodies is an important cause for the absence of green vegetation.

Death from thirst is exceedingly agonizing to man and comes on quickly. Cells strive to maintain life, they struggle

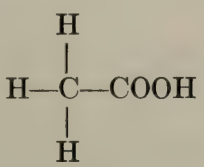
to exist and in case the supply of water is shut off, millions of cells all over the body cannot function because chemical processes cease and the life within is no more. Water is chemically inactive at the temperature possessed by living things, and yet permits the occurrence of important chemical activities at those temperatures; it dissolves the various substances found in protoplasm and thus forms a vehicle for chemical action. It has great capacity for absorbing heat. Also it has great surface tension, which is necessary for absorption that is such a necessary phenomenon in the life of the cell. In addition, water has important electrical properties which have to do with formation of solutions.

(2) *Proteins.*—Among the various compounds that occur in protoplasm, the *proteins* are the most characteristic. Note the resemblance between the words "protoplasm" and "protein." Proteins are absolutely necessary to protoplasm. An animal that receives no protein in its food starves to death. Proteins are compounds of nitrogen, carbon, hydrogen and oxygen. In addition, some contain iron, phosphorus, iodine, and sulphur. Although proteins behave chemically in many different ways, yet the above-named elements are present in all instances in about the same proportion. According to one investigator proteins contain 54.5 per cent carbon, 17.6 per cent nitrogen, 7.3 per cent hydrogen, 23.5 per cent oxygen, and about 2 per cent sulphur. There are all grades between simple protein compounds and those that are very complex. For example, the chemical formula for egg albumen has been stated as: C, 204; H, 322; N, 52; O, 66; S, 2. Some common proteins are: myosin in lean meat or muscle; casein in milk or cheese; albumen in eggs; gluten in wheat flour; and legumen in peas and beans. There is an indefinite number of these compounds.

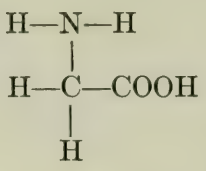
It is altogether probable that the proteins of one animal differ, although ever so slightly, from those in any other animal. So it is well within truthful limits to say that there are at least a million kinds of proteins. Moreover, the pro-

teins of one tissue of an animal differ from the proteins of another tissue. The differences in proteins have been discovered by disintegrating them with superheated steam; by boiling with acids or alkalis; by a study of the action of ferments or of bacteria upon them. Biological analysis by means of ferments and bacteria is more fruitful than crude treatment with acids, etc. Analyzed in the above fashion, a complex protein molecule breaks down into simpler compounds of smaller molecules which resemble the original proteins in many respects. These intermediate compounds are called proteases and peptones. They are formed in the regular physiological day's work of an animal or plant.

The simpler molecules can be further broken down into yet more elementary compounds which in the pure state are crystalline, colorless, and as a rule, tasteless. These are called *amino-acids*. Emil Fischer, a great chemist, called them the "building stones" of the body, for it is from these simple compounds that an animal builds up its proteins. There are eighteen well established amino-acids, and they have been named as follows: (1) Glycine, (2) Alanine, (3) Valine, (4) Leucine, (5) Isoleucine, (6) Caprine, (7) Phenylalanine, (8) Tyrosine, (9) Serine, (10) Cystine, (11) Aspartic acid, (12) Glutamic acid, (13) Arginine, (14) Lysine, (15) Histidine, (16) Proline, (17) Oxyproline, (18) Tryptophane. Recently another amino-acid has been announced. Although they differ from one another in a number of ways, yet all have points in common. For example, each contains an organic acid or carboxyl group of atoms COOH and an NH_2 group of atoms. One of the hydrogen atoms of the organic acid group is replaceable by the amino group of NH_2. Thus the formula for acetic acid is CH_3COOH. This may be pictured as follows:



By substituting an NH_2 for one of the H atoms of the acid, the result is



or this could be more briefly written NH_2CH_2COOH. But this is an amino-acid. It is called glycocoll or glycine, number 1 in the above list of amino-acids.

The amine group NH_2 suggests its relation to ammonia. Ammonia is one product of the disintegration of proteins. This is accomplished in nature by decay-causing bacteria. Other bacteria can change the ammonia into nitrites, and these by still other bacteria into nitrates. Nitrates are absorbed by the roots of plants and finally reach plant cells where with other compounds they are made up into proteins. Plants can make proteins out of inorganic materials, but only when the manufacturing medium, protoplasm, is present to produce this remarkable product. Protoplasm in animal cells *cannot* do this. Animals feed on highly organized proteins. They disintegrate these probably into amino-acids and from them take the kinds needed for the manufacture of their own particular brand of protoplasm.

It is interesting to follow up this fact a little further. Let us say that the protoplasm of one type of tissue is made up of numbers 1, 3, 5, 7, 9, 11, 13, 15, 17 amino-acids. Now the animal in question feeds on proteins that contain 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15. It surely has a great variety to pick from. It does so. It discards numbers 2, 4, 6, 8, 10, 12, 14. But it does not thrive, for if it is restricted to that kind of food it will die because number 17 is absent.

Although a very good idea of the constitution of proteins has been obtained by the above-named methods of analysis, yet efforts to combine amino-acids into compound proteins have not been successful on the whole. Substances having many of the properties of proteins have been synthesized.

These are called peptids. Some day real proteins may be made artificially from amino-acids. In the cell, some proteins are simpler than others. For example, egg-albumen and serum-albumen are called simple proteins. There are also compound proteins present, and from these non-protein groups of molecules can be split off. Proteins are detected by their color reactions to certain chemicals; by precipitating them with mineral acids and other substances, and by coagulating them by heat.

Another important feature of proteins is that they are *Colloids*. This name was chosen by Graham in 1861, from the Greek word for "glue." The chief constituent of glue is gelatin and gelatin is a protein. It is very important nowadays to know just what is meant by a colloid because, above all other things, protoplasm is colloidal. An entire field of present-day chemistry is *Colloid Chemistry*. Graham was the pioneer worker in this field. If we place a little cube of gold having dimensions of 1 mm. along each edge, in a jar of water it would sink. It would not go into solution. If we divide it into a million or billion little cubes these would also sink. However, if we divide the original cube into a quadrillion little pieces and then shake these up in water, they would remain dispersed throughout the fluid. The thousandth part of a millimeter is called a micron. But the ultra-microscopic particles into which we have theoretically separated the gold are still smaller than this. They have a measurement of 0.01 of a micron on each edge. This is called a submicron. Such particles could not be seen with the highest powers of magnification now available. Objects having a size of 200 submicrons are just visible. Such a suspension of fine gold particles in a liquid medium, like water, would be called colloidal gold. It would be gold in the colloidal state. So, after all, a colloid is simply a name for a physical state of matter. Egg albumen and starch paste are familiar examples of colloids. Clouds, dust, smoke, foam, cream and jellies are also colloids. In each case a gas, a liquid, or a solid is suspended or dispersed in a gas, or liquid, or solid.

Proteins, being colloids, do not diffuse through cell walls,

but this complex organization of colloidal matter does absorb substances from without the cell, and analyzes, synthesizes, and oxidizes inside the cell. Observers are amazed at the wonderful operations in a modern automobile factory. Operations infinitely more bewildering occur in living cells.

(3) *Carbohydrates* are compounds of carbon, hydrogen and oxygen, in which the two last named occur in the same proportions as in water. One of the great basic operations of the plant world is the manufacture of carbohydrates from carbon dioxide and water. These carbohydrates constitute the basic fuel of animal life, and animals are dependent upon plants for them. There are three groups of carbohydrate compounds. (1) The Monosaccharids have one sugar group. The formula of a common sub-group is $C_6H_{12}O_6$. Such a compound is specifically known as dextrose, or grape sugar. When two molecules of grape sugar are united with a loss of one molecule of water, then a secondary sugar, $C_{12}H_{22}O_{11}$ is formed. This is a Disaccharid. Cane sugar, milk sugar and maltose are examples. When several monosaccharid molecules are united a Polysaccharid is formed. The formula is $(C_6H_{10}O_5)_n$. The polysaccharid is a multiple of the $C_6H_{10}O_5$ grouping. Common wheat flour is a polysaccharid, as also are potato starch, tapioca and corn starch. A certain amount of starch is stored as a reserve fuel supply in the liver of animals. This animal starch is called *Glycogen*. Vegetable gums are other examples. The delicate cell wall of plant cells, cellulose, is a polysaccharid. So also are cotton, linen and woody stems. Dextrose, $C_6H_{12}O_6$, is one of the first products formed in the leaf of the green plant from carbon dioxide and water. This is carried to seeds or fleshy roots and in some cases to stems (potato) and there changed to starch and stored. The great fuel supply of animals is, after all, starches and these are stored chiefly in seeds such as grain. Converted into wood, the polysaccharid serves also as another sort of fuel supply. Coal was once wood.

(4) *Fats* are found in such seeds as cotton seed and linseed and in various types of nuts. In animals, fat is stored in a certain type of connective tissue called adipose tissue.

Fats contain the same elements as carbohydrates, namely, carbon, hydrogen and oxygen, but not in the same proportion. Chemical analysis reveals the fact that animal fats are mixtures of certain elementary fatty compounds which differ somewhat from each other in structure. These are palmitin, olein, stearin, butyrin. Human fat is chiefly olein. Butter is mostly olein and palmitin, $C_{51}H_{98}O_6$. When purified, fats are odorless and tasteless. Fats boiled with water or steam are changed to two simpler compounds, a fatty acid and glycerine. In the intestine, fats are thus simplified or digested by means of digestive agents, and the fatty acids and glycerine can be absorbed. If fat is left exposed to the air in a warm place it also undergoes decomposition, as stated above. It becomes rancid, i.e., it is acid. Fats deposited in the body are derived partly from the fat that is eaten and partly from carbohydrates and proteins. Adipose tissues aid in maintaining the body temperature. Fat contains potentially over twice as much heat as carbohydrate. As stated above, fat can be converted into carbohydrate, or carbohydrate can be converted into fat. This possibility of transformation is one illustration of the unique properties of protoplasm.

(5) *Inorganic Salts.*—The presence of inorganic salts in protoplasm is easily demonstrated. They are chlorides, sulphates, carbonates, and phosphates of calcium, sodium, potassium and magnesium. Some are used in the formation of bones and teeth. They are very necessary in the chemistry of cell life. Animals die if fed upon substances from which all salts have been removed. It has been found that blood contains a considerable amount of sodium chloride. This salt occurs in the cells also. The concentration of our blood in health corresponds to a 0.9 per cent sodium chloride solution. Frog's blood corresponds to a 0.7 per cent solution. Any increase or decrease from this standard concentration means an upset in normal functional processes. Fever, or increase in temperature, is abnormal. A departure from the normal saline content of cells is also abnormal. These salts must be present in the food and most of them are present in the ordinary diet. Our vegetable foods

do not contain enough sodium chloride so more is added to them. Too much, however, is harmful. Thus carnivora obtain sufficient salt from the flesh of their prey. If our diet were exclusively meat, our food would contain all the salt needed. Herbivorous animals hunger after salt. Some of them travel long distances to " salt licks."

(6) *Chemical Elements.*—The greater part of protoplasm by weight is *carbon.* Indeed, the primary materials of protoplasm are carbon compounds. They are combustible, they unite with oxygen to form carbon dioxide and water and at the same time liberate energy. In the inorganic world, carbon forms a gas with oxygen, i.e., carbon dioxide. This forms 0.04 per cent of the atmosphere.

Hydrogen exists as part of water. It is taken into the bodies of plants and animals in this form and excreted as such. It is of interest to call attention to the fact that water is the most plentiful compound on earth.

Oxygen is available in the free state, and holds a unique place among all the elements on account of this. It is the special function of oxygen to unite with certain compounds of protoplasm, thus giving an example of ordinary oxidation. As a result of this, energy is released enabling the cell to perform its work.

Nitrogen is absolutely essential to protein formation. Without nitrogen there could be no protoplasm. Nitrogen forms 79 per cent of the atmosphere, but this is not to any considerable extent available to the living world. Nitrogen is taken into plant bodies in the form of nitrates. From nitrates and other compounds plants manufacture proteins. Herbivorous animals eat plant food and utilizing plant proteins, reconstruct their own particular types of protein. Carnivorous animals, feeding on flesh, convert this type of protein into their own particular types. Ammonia, a nitrogen compound, is one of the chief products formed in the " decay " of plants and animals, which process is accomplished by means of bacteria. Other bacteria change ammonia eventually to nitrates, in which form nitrogen is absorbed by plants, as stated above.

Sulphur usually occurs in the soil as calcium sulphate.

Absorbed by plants, it is used in the manufacture of certain amino-acids. In these amino-acids, animals find the sulphur necessary for the manufacture of their particular type of protoplasm. Sulphur is again returned to the soil in the form of sulphates.

Iron is indispensable for the maintenance of life of most organisms. It is necessary for the formation of the green substance, chlorophyll in plants. Without chlorophyll plants could not make carbohydrates from water and carbon dioxide. Iron is also a vital constituent of certain blood cells. Without the iron compound oxygen could not be conveyed from the lungs to the tissues. In certain lower animals it is interesting to note that copper plays the part of iron in this respect. When the blood of such animals has absorbed oxygen it is blue-green in color. Iron is supplied to the body by meats and green vegetables, such as spinach. The body conserves its iron carefully.

Iodine should also be present as part of the water supply or in foods. A lack of it causes disease.

Phosphorus is absorbed by plants as phosphates. Certain vitally necessary constituents of living cells (lecithin and nuclein) are compounds of phosphorus. No other element will suffice.

Calcium, *potassium*, *sodium*, *chlorine* and *magnesium* are necessary companions of proteins and the other more distinctive protoplasmic compounds. They undoubtedly have vital relations with them, as indicated above.

Silica occurs in practically all plants and animals and in considerable amounts in certain plants.

Bromine is present in simple aquatic plants. *Aluminium* has been found in plants. All these elements occur in the inorganic world. When they are taken up they form part of the living plant. They may then become food for a living animal. Eventually they return to the inorganic state, only to be again taken up into living things. This is termed "the cycle of the elements."

History of Ideas Concerning the Physical Basis of Life.—When it was recognized that plants and animals are composed, in the main, of similar ingredients, it became possible

to consider them in the same category and to establish a general science of living things. This we call *Biology*. To show how this general idea developed is, therefore, interesting. At one time botany was thought to have no more connection with zoology than with chemistry. Many people studied this material of life in the past. Felix Dujardin in 1835, in France, made a very careful study of protoplasm, as he found it in single-celled animals and in worms. He said that the substance found in these two different sorts of animals was essentially the same, and described it as a jelly-like substance endowed with life. He experimented with it. When treated with reagents like alcohol, nitric acid, and potassium compounds, he found the effect similar. The name he proposed for it was *sarcode*. This word is used to-day in modified form for certain protoplasmic parts of muscle tissue. Purkinje, a Bohemian, studied eggs and embryos, about 1840, and thought that they were made up of essentially similar materials, for which he proposed the name protoplasm. Hugo Von Mohl, in 1846, studied the living substance in plants. He found it to be mucilaginous and granular and called it *protoplasma*. Naegeli, some time before this, had found that it was nitrogenous. Von Mohl published so much along this line that the word protoplasma came into general use as applied to the living part of plant tissues.

Often men have very correct ideas concerning matters which they have not investigated. Many observations have to be made, however, and a possible statement or explanation becomes part of scientific knowledge only after complete investigation proves the idea to be true. Cohn at Breslau, in 1848, wrote: " If the living substance of plants and animals (i.e., sarcode and protoplasma), are not identical they must be at any rate in the highest degree analogous." In the fifties another investigator, De Bary, a botanist, examining queer slimy masses which grow on dead stumps and which are very simple plants, said that they greatly resembled the sarcode of certain animals. Virchow, the pioneer in pathology, made many new studies of this substance as he observed it in diseased tissues.

Max Schultze (Fig. 2) settled the matter. He made many new observations of his own on material obtained from many different plants and animals; summarized all the previous knowledge; added much more, and in 1861 published a paper announcing that although this living stuff of plants differed from that found in animals, yet it was essentially the same; that the points in which it was similar were remarkable when one considered the various sources; and he said that fundamentally plants and animals are alike in that both are composed of a material which was unique in nature and he rechristened it *Protoplasm*. Thus a coalition was formed between the two sciences of botany and zoology, and *Biology*—the general science of living things, was born. Max Schultze has been called the "Father of Modern Biology." He was a professor at the University of Bonn.

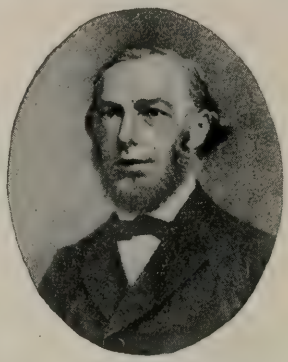


FIG. 2.—MAX SCHULTZE (1825–1874).

(From Locy—Biology and Its Makers.)

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CHAPTER III

THE CELL

Definition.—Protoplasm of which living things are composed does not occur indefinitely distributed, but is organized, as stated, into units called *cells*. Organs are made up of tissues which in turn are made up of cells. In science there are many units such as the atom, gramme, centimeter, ohm, watt, and calorie. The biological unit is the cell. A preliminary definition is that it is a minute organization of protoplasm capable of performing life functions.

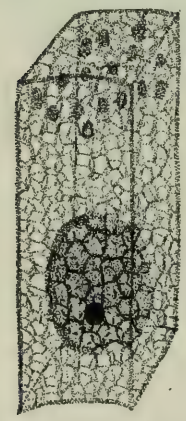

FIG. 3.—DIAGRAM OF A CELL.

At the basal end is indicated the Nucleus with a Nucleolus. The dark network in the Nucleus is Chromatin. The alveolar nature of the Cytoplasm is indicated. At the free (upper) end are Granules, representing cell secretions.

Morphology of Cells.—The morphological study of cells constituted the main work of cytology up until recent times. Microscopic study reveals several structures possessed by cells in common. It is impossible in beginning this work to gain any adequate conception of cells. Later the student can review the matter from the broader standpoint of the study of plants and animals. Very important phases of cellular biology will be presented in the study of embryology and also in the study of genetics.

(1) *Cytoplasm.*—A cell is composed of two regions: first the *Cytosome* or cell body and, second, the *Nucleus*. (Fig. 3.) The protoplasm outside the nucleus or constituting the cytosome is called *Cytoplasm* and that of the nucleus the *Nucleoplasm*. Nucleoplasm differs chemically from cytoplasm.

Preparations of tissues stained in different dyes indicate that cytoplasm has an affinity for acid dyes and nucleoplasm an affinity for basic dyes.

Consider first the morphological features of the cytosome. In the first place the cytoplasm possesses all the features noted above in the discussion of protoplasm. It may or may not possess a cell wall. Plant cells (Fig. 4) have a cell wall made of cellulose. Some single-celled animals have a wall about them of a kind of horny material. In most animal cells the cytoplasm is held intact by a clear, somewhat condensed layer of protoplasm, the cell membrane. Plant cells may contain little bodies called *plastids*. Some of these contain a green substance, chlorophyll, and are called *chloroplastids*.

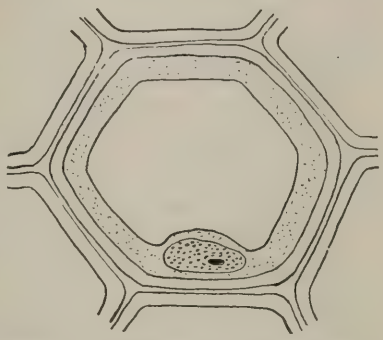

FIG. 4.—DIAGRAM OF A PLANT CELL.

Inside the Cellulose Wall is a thin layer of Cytoplasm, at one side of which is the Nucleus. Inside the Cytoplasm is the Sap cavity.—(From Sinnott's Botany.)

Chlorophyll is a complex protein containing magnesium. It plays an essential part in the manufacture of starch from carbon dioxide and water. Iron is necessary for the production of chlorophyll, but is not present in it. The cells in some flowers and fruits contain colored plastids which are called *chromoplasts*. In some cells, spherical spaces evidently filled with liquid appear at times. These are *vacuoles*. In single-celled animals, liquid waste substances gather in this way. When they are discharged another vacuole forms. The cytoplasm may also contain for a time the products of cell manufacture as granules in gland cells of the pancreas. Discharged from the cells these granules are apparently dissolved and appear outside of the cell in liquid form. Adipose tissue cells contain relatively enormous globules of fat which the cell must have manufactured. The potato is a mass of countless cells

filled with starch grains which are stored there. These starch grains have been formed by the protoplasm of the cell from sugars which have been absorbed. In the cell contents of the single-celled animals, simple plants or dead husks of plants or skeletons of animals are often found, which have been engulfed. In addition to the above objects which are visible, the cytoplasm probably contains substances in liquid form such as useful secretions and useless wastes which remain for a short period before discharge from the cell. Near the nucleus at times a little star-like body is found. This is the *centrosphere*. In the center is a little dot called the *centrosome* and from this radiate protoplasmic fibers which constitute the *aster*. This whole apparatus is sometimes called the *attraction sphere*.

(2) *Nucleus*.—The Nucleus is as a rule spherical. In long narrow cells the nucleus is elongated. It may be strung out like beads. In some cases there is more than one nucleus. In bacteria there is no distinct nuclear body, but it is believed that nuclear material is distributed in the form of granules throughout the cell. Some red blood cells have no nucleus, and, as a consequence, they are apparently able to exist only a comparatively short time. The nucleus contains a liquid compound which is interspersed with a network of fibers called *Linin*. Gathered along these fibers of linin is a mass of granules which are somewhat heaped up where the fibers cross. These granules are called *chromomeres*. The totality of chromomeres is called *chromatin* because of its great affinity for certain dyes. Chromatin is the vehicle of inheritance. It carries over from one generation to the next the qualities inherited. In the nucleus is often found a little spherical body called the *nucleolus*. Possibly two of these occur. In spite of a great deal of research, there is still no general agreement as to just what the function of this body may be. Possibly it is a temporary mass of waste matter, possibly it contains material used for a time in the process of cell division.

(3) *Polarity*.—Many cells are organized in such a manner that they exhibit a property known as *Polarity*. This suggests an axis. The nucleus of a pancreas cell, for example

(Fig. 5), is toward the inner end, while the products of secretion collect near the free end from which they are later discharged. In the eggs of certain animals the head will develop from the protoplasm of one end, the tail from the protoplasm at the other end, and the trunk from the middle part. In some cells there are indications of this axis and this polarity. However, the real polarity is an internal organization which cannot be seen.

(4) *Size.*—For the most part cells are microscopic in size. Some single-celled animals can just be seen with the naked eye, and look like tiny white specks. However, most cells are very much smaller. It has been claimed that most of our own cells are $\frac{1}{5000}$ of an inch in diameter. Yeast cells are about $\frac{1}{3000}$ inch in diameter. Bacteriologists believe that some bacteria are so small that they cannot be seen with the most powerful microscope. Their presence is indicated by the effect they produce on special substances. Animals of different size have cells which are of about the same size. For example, the elephant is composed of an enormously greater number of cells than the mouse. The hen's egg is a single large cell, yet the shell and the white are not part of the cell, but merely associated with it. The egg cell nucleus is a tiny microscopical structure on the top of the yolk. The ostrich egg is still larger, but this is because there is so much more yolk present. The egg of the elephant is microscopic in size. The number of cells in an organism depends on its size. The human body contains millions of cells. The remarkable thing is that this is a community containing more members than the population of the earth, and in health these units get along reasonably well together. For the greater part of the time they are at

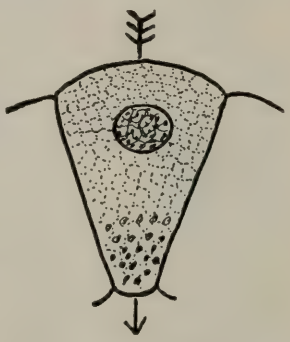

FIG. 5.— DIAGRAM OF A PANCREAS CELL.

Near the base is the Nucleus. Near the free end, granules are shown. The arrow indicates the axis. Food for the cell is taken in at the basal end and secretions are discharged at the free end.

peace with one another. There is no poverty here, no disturbing questions of capital and labor, and none of the other distressing problems which bother the greater organism of human society.

(5) *Shape.*—Cells vary greatly in shape (Fig. 6). In most cases single free cells are spherical. This is apparently determined by the same physical forces that determine the contour of a drop of water or jelly. The egg cells of many animals are little spheres. Masses of soft-walled cells of the same kind are spheres with flattened sides as would be expected if soft spheres of about the same size were to be placed in a mass. We find examples of this in parenchyma tissues of plants. However, in many cases the shape is evidently determined by an internal organization. Attention will later be called to the many shapes of single-celled animals, even though no rigid limiting membrane is present.

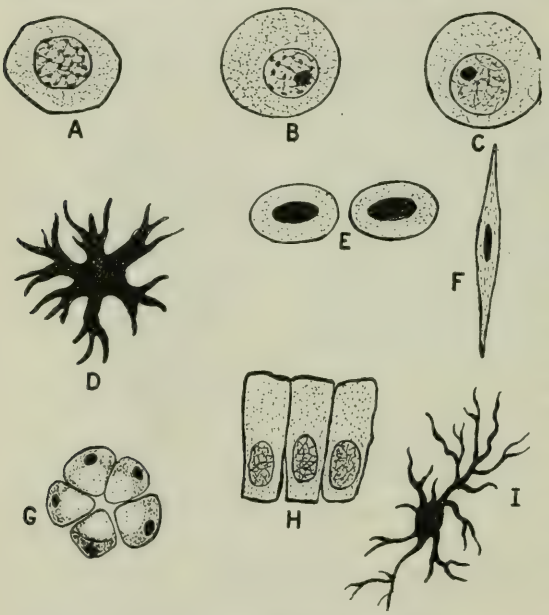

FIG. 6.—VARIOUS SHAPES OF CELLS.

A, Egg cell of human infant; *B*, Egg cell of cat; *C*, Egg cell of sea-urchin; *D*, Pigment cell from skin of frog; *E*, Red blood cells from frog; *F*, Smooth muscle cell; *G*, Five pancreas cells; *H*, Columnar epithelium; *I*, Nerve cell.

Physiology of Cells.—The cell is more than a morphological entity, it is a living thing. As such it is the locus of many activities.

A. Physio-chemical.—Cells must take in water, salts,

food and oxygen. As a result of the life processes within, wastes accumulate. These must be discharged. Such exchanges take place through the living membrane of the cell. Certain physical phenomena occur in the accomplishment of this.

(1) *Diffusion.*—When certain dyes are added to water, small particles of the dye dislodge themselves and move through the water until the entire mass of the dye is evenly distributed. If sugar crystals are added to water the same thing takes place. This process of the even distribution of the molecules of one substance between the molecules of another is known as *diffusion.* When substances are absorbed into a cell they also diffuse throughout it. When sugar is thus dispersed in water it is called a solution. We have shown above that protoplasm is a sort of solution. Diffusion is one of the physio-chemical phenomena occurring in living cells.

(2) *Dialysis.*—If we place a quantity of egg albumen, salt, and water in a parchment tube and suspend this in a beaker of water, and later test the water without, we will obtain positive tests for salt, but none for albumen. Apparently the membrane has permitted the molecules of salt, but not the albumen to pass through. The membrane is permeable to one but not to the other. The cell wall is this sort of a membrane, through which salts and sugars can enter cells, while the protein compounds of the cell are kept within. This phenomenon of the selective action of membranes is known as *Dialysis.*

(3) *Osmosis.*—Membranes are known to differ in permeability. In some cases the membrane will not readily permit the salt to pass through, but will allow the water to pass. Living cell membranes show that they possess this same power. If we tie a piece of such a semi-permeable membrane over the end of a thistle tube, fill the bowl of the thistle tube with a strong solution of salt, and immerse this in a vessel of water, we will find some time later that liquid rises in the stem of the thistle tube for some distance. Indeed, if we made this rising column of liquid press against a weight we would have evidence of considerable force or

pressure. Such a force is known as *Osmotic Pressure.* The phenomenon involved is called *Osmosis.* As stated above, blood contains salts in solution, and the concentration of the blood is equivalent to a 0.9 per cent salt solution. If red blood cells are placed in distilled water, they swell and later burst, discharging their contents. What has happened is that osmosis has taken place through the cell membrane. The distilled water has passed through, but the salts within have not been able to pass out and considerable internal pressure has been developed, so much so that the surface tension of the cell membrane is able no longer to withstand the pressure and the bursting follows. Or we can place the red blood cells in a concentrated salt solution. In this case water passes out of the red blood cell, and we have *exosmosis* instead of *endosmosis.* As a consequence the cell is shriveled and broken up eventually. This phenomenon does not occur normally because the concentration within the red blood corpuscle is the same as that of the liquid part of the blood. In other words, the blood plasma is *isotonic* to the contents of the blood corpuscle. If the plasma were less concentrated it would be *hypotonic* as in the first experiment. If more concentrated, it would be *hypertonic.* All the cells of the body resemble the blood cells in this respect to a certain degree. They have, as a rule, a certain internal concentration. They are bathed without by liquids of varying concentration. If there is not a condition of isotonicity between the two, or if the difference becomes great enough, then osmosis great enough to injure the cells will certainly take place.

(4) *Ionization.*—Certain substances form crystals under the right conditions. Such substances are known as crystalloids. Sugar and salt are familiar examples. Urea, a product of excretion of animals, can be obtained in the crystalline form. Gelatin is not a crystalloid but a colloid. It was formerly thought that this was a good distinction between crystalloids and colloids. It was stated that protoplasm was a solution of crystalloids in which colloids were dispersed and that proteins could not occur as solutions. It has since been found that some colloids can be obtained

in crystalline form. Now some compounds in solution not only break up into dispersed molecules, but the molecules themselves break up into simpler parts called *Ions*. Thus salt, NaCl, breaks up into Sodium Ions and Chlorine Ions. Moreover, each Ion bears a charge of electricity that is either positive or negative. Thus the sodium ions bear a positive charge and the chlorine ions bear a negative charge. Those ions which carry negative charges are called *anions*, and those that are positively charged are *kations*. Crystalloids which in solution break up into such Ions are called *Electrolytes*. If a current of electricity is passed through such a solution the kations (positively charged ions) travel toward and collect at the negative electrode, while the anions travel toward and collect at the positive electrode, due to the fact that unlike electric charges attract one another. Sugar, another crystalloid, does not break up into ions, and does not ionize in solution. We call such substances, *non-electrolytes*. Colloids are non-electrolytes. Ionization is a phenomenon which must be investigated in connection with the basic physiology of cells. The reason is, that cells contain electrolytes. Indeed, the osmotic pressure of electrolytes is almost twice that of the same concentration of non-electrolytes.

B. Reaction of Fluids that Bathe Cells.—Chemically speaking, some solutions are acid, others are alkaline. It has been found that the acidity is due to the excess of free *Hydrogen ions* which are present. Alkalinity is due to the presence of an excess of *Hydroxyl Ions*, that is, oxygen-hydrogen ions. The degree of alkalinity was formerly measured by determining the amount of acid that must be added to neutralize the alkali. Acidity was measured by determining the amount of alkali that neutralized the acid present. Formerly this was done by adding an indicator to the acid solution in question, and adding an alkali of known strength until the neutral point was reached. The reverse process was employed to determine the degree of alkalinity. It was found, however, that this method did not give the real degree of acidity or alkalinity. This can only be determined by ascertaining the

number of hydrogen or hydroxyl ions present. In other words, the *Hydrogen-ion Concentration* must be found. Simple and accurate colorometric methods, or even better electric methods, have been devised for doing this. What is the bearing of all this on cell physiology? Just as the temperature of the human body must remain constant for the normal physiological functioning, so the reaction of the blood must remain constant. Any departure toward alkalinity or toward acidity tends to prevent the normal activities of cells. Most people would not suspect that the reaction of tap water is different from that of distilled water. Yet Hawk states that if the reaction of the blood becomes acid to a degree equal to the ratio of tap water to distilled water the result would be fatal.

Investigations of the forces connected with the activities of atoms, ions, and molecules of chemical substances in solutions constitute a great part of the field of physical chemistry. Biologists, by using the facts of physical chemistry and exploring into the physiological unknown, hope to explain some of the very fundamental phenomena of life.

C. Enzymes.—It has been stated above that one type of carbohydrate or protein or fat could be changed into another form by subjecting it to strong acids or superheated steam, etc. But similar changes are occurring constantly in the body at relatively low temperatures. This is accomplished by means of compounds called *Enzymes* (or Ferments). It is a familiar fact that fresh milk or cooked fruit, if exposed to the air for extended time, will turn sour. Acid has been formed due to the presence of an enzyme. In inorganic chemistry chemical changes are hastened if certain other substances are present. Chemists speak of these as *Catalysts*, something which breaks down but does not enter into the reaction itself. Enzymes are organic catalysts. That is, they are catalyzers that are made in living plant and animal cells. Although to-day there are known to be a good many enzymes, it is probable that in time a great many more will be discovered. Probably no living cell exists without a whole group of enzymes. A further account of them will serve to make possible a better under-

standing of their characteristics. In the first place, they are organic compounds and probably protein-like and *colloidal*. They act in very small quantities and are not changed although they hasten changes. Heat easily destroys them. They are specific, i.e., one enzyme can bring about only one type of reaction. Some are effective in an acid medium, others in an alkaline medium; while some are active only inside the cell, i.e., are *intracellular*, others acting outside the cell, are *extracellular*. Some cause large molecules of a substance to absorb water and form a simple compound. This is known as *hydrolysis* and such an enzyme is *hydrolytic*. Oxidases bring about oxidation. Deaminases break down proteins. Coagulases coagulate soluble proteins. They are also named from the specific materials on which they act, i.e., Ureases break down urea; Amylases change starches; Proteases act on proteins; Lipases act on fats. There is evidence that enzymes exist ready for action, but are prevented from acting by the presence of anti-enzymes. Coagulation of blood cannot occur in the body because of the presence of an anti-enzyme. In the stomach are compounds no more complex than the stomach wall itself and they are "digested" or broken down by means of enzymes. Why does the wall of the stomach escape the action of the enzymes inside it, which come in contact with its walls? It is thought that the living wall contains anti-enzymes. After death enzymes within the cells of an organ are released from the bondage in which they are held in life by anti-enzymes and thus are free to digest the organ in which they were formed. This is known as *Autolysis*, or a kind of self-destruction. A most important characteristic of enzymes is that apparently their action is reversible. They can build up or break down.

D. Metabolism.—Life is a constant succession of construction and destruction. The term *anabolism* is applied to constructive processes and *katabolism* to destructive. The resultant of these processes is life. By a balance between these two, life is maintained. The processes involved constitute what is known as *Metabolism*. There are certain universal processes involved in metabolism. (1) *Secretion:*

This involves, for example, the manufacture of enzymes. (2) *Digestion:* This is a chemical disintegration of foods by means of enzymes. (3) *Respiration:* This means the absorption of oxygen by the cell. (4) *Circulation:* This means the diffusion of the digested material and oxygen throughout the cell. If the oxygen and food is obtained from some point at a distance from the cell, circulation and respiration demand special organs. (5) *Oxidation:* This is the union of oxygen with some compound resulting in the liberation of energy used in activities of many kinds. Oxidation in cells takes place by means of enzymes called oxidases. (6) One type of activity is the building of protoplasm, i.e., more proteins, more carbohydrates, more fat. This is *Assimilation*, concerning which very little is known. Plants differ from animals in their ability to *construct* carbohydrates and protein from the inorganic. (7) *Excretion* is the discharge of waste materials of metabolism. Carbon dioxide, water and nitrogenous compounds, such as urea, are waste materials. Excretion is a kind of secretion.

E. Adjustment.—Free or associated cells are more or less directly in constant relation to changing external conditions. These most certainly have a profound effect on the continued existence of the cell. The cell must meet these changes. It must adjust itself. We will refer to these extra, but still related, metabolic activities as phenomena of *Adjustment.* Cells are able to adjust or adapt themselves because they possess at least three properties. First, *Irritability.* Cells are especially sensitive to sudden changes. Such sudden and appreciable changes as evoke responses from cells are known as *stimuli.* There are various kinds; *Physical*, such as a sudden change in intensity or color of light, a sudden mechanical contact with the cell or a sudden change in temperature, a sudden change in strength of an electrical current, or possibly a sudden change in sound. We have enumerated *photic, mechanical, thermal, electrical* and *auditory* stimuli. Secondly, stimuli may be *Chemical*, i.e., some sudden change in the chemical organization of the substances outside the cell. Because of these stimuli the cell equilibrium is changed in some way. Also because

of the disturbance in equilibrium a change is conducted to various parts of the cell. Thus protoplasm possesses the property of *Conductivity*. What is conducted is a sort of chemical and physical change called an impulse. Finally the protoplasm of the cell responds to the conducted impulse. And this, in the case of muscle, appears as a *Contraction*. If the cell comes into immediate contact with the external world and must make a new adjustment to it, then these three properties are involved, namely, *irritability*, *conductivity*, and *contractility*. Certain cells of higher animals are devoted to but one of these processes. For example, certain cells in the eye are stimulated by light; certain cells in the nervous system conduct impulses aroused by this light stimulus; and certain units of muscular tissue contract and put the whole organism into the right relation to this light stimulus. On the other hand, a cell in the stomach is not immediately concerned. All cells, no matter how specialized they are, possess to some extent, these three general characteristics, as well as those of metabolism.

F. Reproduction.—In addition to Metabolism and Adjustment, there remains a great physiological activity of cells called *Reproduction*. Death occurs to particular organizations and at the same time the stream of life continues. A general characteristic of organisms, single or many celled though they may be, is that they have the ability to continue the protoplasmic organization which they themselves express. Their plan of organization is reproduced in the body of their offspring. For example, a single-celled organism divides in two after it has lived for a certain time. The two daughter cells are its offspring, and thus two new individuals are formed.

In the case of the larger organizations of many-celled animals or plants, reproduction is accomplished by the separation from the parent organism of a small portion of protoplasm, which has the power of developing into an adult like the parent. Some biologists have attempted to show a necessity for this. They explain it in terms of single-celled animals, which start in life as half a parent cell.

As it grows the surface increases as the square of the diameter while the mass or volume increases as the cube of the diameter. Mass increases more rapidly than surface. As all food, water and oxygen are taken in through the surface, and excretion is through the surface also, the amount is limited by the surface area, and there comes a time when the surface is not able to take in sufficient food to feed the more rapidly growing mass. When the cell is small the differences between total surface area and total mass are not so great. They become greater with the increase in size. When this danger point is reached, equilibrium is restored by the simple expedient of cutting the cell in two again. The problem, however, is not as simple as this. Even single-celled animals are not constantly feeding so that surface area is not completely used. From this point of view there is no reason why they could not grow much larger. It is not a question of the relation of surface to mass that determines that the egg of one shall develop into a mouse and of the other into an elephant, though both egg cells may be of the same size and of the same general appearance. Reproduction on the whole involves the separation, from a parent organism, of living matter which has the *power of developing* into a similar organism. The rest of the old organism dies, but its line is continued in the body of its offspring. This phenomenon of reproduction is in no way less important than metabolism or adjustment. With it are associated many great biological questions such as genetics and evolution.

G. Growth.—After reproduction comes growth. When a single-celled organism reproduces by simply dividing into two daughter cells, each about half the size of the mother cell, then each daughter cell takes in food and by metabolic processes manufactures new protoplasm, thus increasing to a size like the mother cell. This is growth. In the case of complex organisms, growth involves more than this. It also involves much cell division. It entails increase in differentiation, i.e., the specialization of various tissues and complicated organs and systems of organs. It is even more than this. It involves organization or integration of

the countless cells, the various tissues, the many organs and the systems of organs into a smoothly working unit system or *Organism*. Organization was present at the beginning and is present at each moment of development and all during the life of the organism.

H. Protoplasmic Motion.—In the case of some cells the protoplasm inside the cell is in motion. What causes this is not known. There are a number of kinds of protoplasmic motion. The plant cell has a cellulose wall. In some plant cells there is a thin layer of protoplasm just inside the cell wall. The nucleus lies in this somewhere along the wall. Green chloroplasts are found in this protoplasmic layer, and the interior of the cell is filled with watery sap. In some plant cells, as in *Anacharis*, the protoplasm rotates round and round the cell, carrying the chloroplasts in this streamlike current. In the single-celled animal, *Paramecium*, at times a rotating stream of protoplasm, can be clearly made out. The contraction of a muscle cell is a more familiar example of protoplasmic motion. Some cells have minute protoplasmic projections called *cilia* which have a quick whip-like motion. Other cells have a long thread-like process called a *flagellum* whose movement effects locomotion in single-celled animals.

History of Ideas Concerning Cells.—In the seventeenth century the compound microscope had come into use. An Englishman, Robert Hooke, examined many objects with this new and fascinating instrument. He cut cork into thin slices and studied these. He noted that cork was an assemblage of little box-like units. He called these *cells*. Contemporaries of his in other countries also studied thin preparations of plant tissues microscopically and even drew diagrams of somewhat similar " cells " but overlooked their importance. In 1759 a young German embryologist saw little "globules" in early embryos. Even Bichat, the founder of Histology, (1771–1802) in spite of all his microscopical investigations, did not really see their actual structure. Oken, a somewhat fanciful philosopher, in 1808 stated that he could easily prove " that animals and plants were nothing but numerous aggregations of vesicles " but his

mere statement carried no conviction. During the early years of the nineteenth century the idea was developing that animals and plants were, after all, composed of "globules." In 1831, Robert Brown ascertained that in each globule was an inner body, the nucleus.

At this time in Germany, a botanist, Schleiden (Fig. 7*A*), was studying the minute structure of various plants in greater detail than ever before. He repeatedly found that the underlying structure of all was a definite unit. He even saw the nucleus and thought that the nucleus

FIG. 7A.—M. SCHLEIDEN (1804–1881).

(From Locy—Biology and Its Makers.)

FIG. 7B.—TH. SCHWANN (1810–1882).

(From Locy—Biology and Its Makers.)

formed the cell. Though he was wrong in this, his main contention was correct. He told Theodor Schwann (Fig. 7*B*), who was working on animal tissues, of his discoveries. Schwann immediately thought of the similarity of Schleiden's plant units to those he had observed in the spinal cord. It occurred to them that all plant and animal structures were compositions of cell units. In 1838 Schleiden published an account of his work and made such a declaration. In 1839 Schwann published a more complete and careful review of the whole question. A free translation of the title of his monograph is "Microscopical Researches into the Similarity of Structure and Growth of Plants and Animals." One of his statements is interesting.

" The elementary parts of all tissues are formed of cells in an analogous, though very diversified manner so that it may be asserted that there is one universal principle of development for the elementary parts of organisms, however different, and that this principle is the formation of cells." It should be said here that although Schwann was led to his conclusions regarding the cellular nature of all organisms by a study of the nervous system, yet it was not until the latter part of the nineteenth century that it was finally accepted that even the nervous system must be included in the general law. The special application of this to the nervous system is known as the "*Neurone Theory*"—a neurone being a special name for a nerve cell. Both Schleiden and Schwann were wrong in details, but their general conclusion was right.

After the introduction of the cell idea, there followed a tremendous amount of work on the detailed structure of cells. Then it became evident that the cell was the locus of physiological activities and the physiology of an organ was to be explained by finding out the physiology of its cells. The importance of the cell in the science of embryology was recognized and embryology saw a new development. The greater importance of the cell in heredity was made clear and much work along this line is continuing at present. In 1861, when Schultze made his great generalization he emphasized the fact that cells are masses of protoplasm, each containing a special mass of protoplasm—the nucleus. In 1855 it was accepted that new cells could arise only from preceding cells. Cells could not arise *de novo*. Virchow introduced a now famous phrase " *Omnis cellula a cellula.*" Wilson says with regard to the Cell Theory that " No other biological generalization save only the theory of organic evolution has accomplished more for the unification of knowledge."

Thomson says " that the cell doctrine has three aspects: (1) Morphological, i.e., that all plants and animals are composed of cells; (2) Embryological, i.e., every organism begins life as a single cell; (3) Physiological, i.e., the functions of higher organisms are expressible in terms of the activities

of their cells." "Each cell" said Schleiden in 1838, "leads a double life, one pertaining to its own development which is independent and a second as an integral part of a plant or animal." Schwann expressed this idea in these words, "The whole organism subsists only by means of the reciprocal action of the single elementary parts." Virchow, in 1859, said, "Every animal appears as the sum of vital units, each one of which bears with it the characteristics of life." Thomson has put it thus, "These conclusions combine in impressing us with the unity of organic nature, for although a plant cell is often very different from an animal cell, and one animal or vegetable cell may be very different from another in the same or another body, yet the points of agreement in structure, in development and in function are at least as striking as the observable differences, and often more striking." [1]

Vitalism and Mechanism.—Protoplasm and cells are not merely mixtures of complex materials. Brucke, in 1861, stated, "We must ascribe to living cells, in addition to the molecular structure of organic compounds which they contain, still another and otherwise complicated structure (property or characteristic); and this is what we designate by the term organization." Inseparably connected with physical and chemical ideas of protoplasm is the functioning of protoplasm. Inseparably connected with the societies of cells must be an integrative activity of the whole mass as a unit. This organization cannot be dissected; it cannot be seen with the aid of a microscope. It is not material in the ordinary sense of the word. This has led to the development of two general ideas or schools of thought—*Vitalism and Mechanism.* The vitalist says that life is more than mere physical and chemical forces and that we have not yet been able to elucidate what life is. The mechanist claims that life activities are no more nor less than exhibitions of known physical and chemical laws. Some mechanists, in fact, have a tendency to present explanations of life processes in terms far too simple to fit the known phenomena. One result. however, of the

[1] "Science of Life," 1909.

vitalistic idea is to stifle investigation. The mechanistic position has done more to stimulate research, and many valuable discoveries have, as a consequence, been made.

The truth of the matter probably lies in this direction. Investigators in physics and chemistry know very well that all the knowledge they possess to-day concerning matter and force does not begin to reach the bed rock. Nature is still, to a great extent, *unknown* to them, but they are making new discoveries constantly. The biological mechanist who confidently asserts that life processes are merely exhibitions of phenomena taking place according to known laws of physics and chemistry is open to criticism fully as much as the vitalist. The salvation of the mechanist is that he keeps busily at work, feeling that his problems are ones that can be solved and that his discoveries will prove his theory to be right. The tendency of the vitalist is to do nothing because such things are beyond the powers of man to fathom. When life phenomena are really understood it may be that this so-called life force or " vital spirits " will be identified as a form of energy.

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Part II.—THE BIOLOGY OF PLANTS

CHAPTER IV

THE ALGAE

General Characteristics of Plants.—Botany is that branch of biology that deals with plants. A plant is either a single living cell as a bacterium, or an organization of cells as a rosebush. All the functions of life exhibited by animals are also observed in plants. Plants carry on similar processes of metabolism and of adjustment to external forces, also they reproduce. However, certain peculiarities of structure, and the ability to do certain things which animals cannot do, mark off this group of organisms from the animal group. For example, the protoplasm of the cell is enclosed in a more or less rigid box made of a substance called cellulose. Something akin to this forms the wood of trees. As a result, plants as a whole do not possess the active movements of animals. Animal means animated, i.e., moving about. Most plants do not move about. They are more or less stationary. Another great characteristic of plants is that they have the ability to make carbohydrates from the carbon dioxide of the atmosphere and the water of the earth. Inorganic compounds are absorbed by plant cells from the soil and the protoplasm within has the ability to make new protoplasm from simple carbohydrates and these soil compounds. Animals cannot do this. The plants are nearer to the inorganic world than are animals. Not being able to move much, plants do not possess muscle systems, although there is ample evidence of protoplasmic movement within the cells themselves. Being more stationary, they do not make rapid responses to external changes, therefore they do not possess well-recognized organs of sensation and conduction. They do not have eyes nor ears nor brains. Nevertheless, they are

sensitive to external stimuli and something akin to nerve impulses are present.

About a quarter of a million kinds or species of plants have been given accurate descriptions. No one knows how many different kinds of plants there are in existence. New forms are being discovered constantly. According to kinds of organization exhibited, plants are usually divided into four groups. Each group represents a type plan. This artificial arrangement of the multitudinous forms present in nature is made by botanists for the sake of convenience. Other arrangements are possible. The four great groups of plants are: (1) *Thallophyta*, (2) *Bryophyta*, (3) *Pteridophyta, and* (4) *Spermatophyta.*

The Thallophytes.—The Thallophytes are the simplest of plants from a morphological or structural point of view. According to evolution, the simplest forms of life came first. Thus the Thallophytes would be the oldest plants. They have no stem, no root, no leaf. There are two groups of them. Some possess the green coloring matter called *Chlorophyll.* Possessing this, they can make carbohydrates from carbon dioxide and water and can live independent of other organisms. Such forms constitute the *Algae.* The members of the second group have no chlorophyll, they cannot make carbohydrates from inorganic constituents. They must obtain food already made and therefore are dependent or parasitic. Such Thallophytes are called *Fungi.*

PHYLUM I. SUB-PHYLUM I. ALGAE

The Algae are divided into four sub-groups called the (*a*) *Cyanophyceae*, (*b*) *Chlorophyceae*, (*c*) *Phaeophyceae*, and (*d*) *the Rhodophyceae.* These can be referred to more easily as the Blue-greens, the Greens, the Browns, and the Reds. They are different in color, as indicated, but along with the differences in color, are differences of structure and organization. Most Algae live in water or damp places.

(*a*) **The Blue-green Algae. Cyanophyceae.**—1. *Gleocapsa.* (Fig. 8).—This is one of the simplest of all plants.

It is a single cell with a jelly-like wall. It is blue-green in color and no nucleus is evident, though it has nuclear material. It reproduces by dividing into two cells. The new cell walls swell up and are still contained inside the jelly formed by the parent cell. Each of the two cells may

FIG. 8.—GLEOCAPSA.

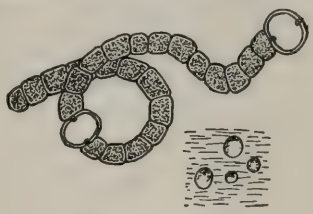

FIG. 9.—NOSTOC.

divide and a cluster of four cells remain together. Microscopical examination of Gleocapsa reveals the cells as small dots surrounded by layers of this jelly-like material. Thus groups of cells are formed. When a certain number accumulate they have a tendency to break apart into smaller colonies.

2. *Nostoc.* (Fig. 9.)—In this case we find a linear arrangement of spherical cells forming filaments resembling a chain of beads. The filament is surrounded by a jelly-like mass. At intervals in a chain will be found a larger clear cell called a heterocyst. It is thought that when a filament breaks, it breaks next to a heterocyst.

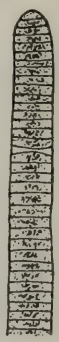

FIG. 10.—OSCILLATORIA.

3. *Oscillatoria* (Fig. 10).—This blue-green Alga is a filamentous form. But the individual cells are short cylinders. There is no jelly-like matrix about the filaments. The filaments sway back and forth in the water. It also has a creeping form of locomotion. We have found colonies of Oscillatoria on the side walls of aquaria. Any cell in the filament as in the case of Nostoc may divide in two, thus increasing the length of the filament. A filament may break in two and by division of its cells make the short pieces into long pieces.

Filaments suggest the border line between single-celled and many-celled organizations. The cells of the blue-green Algae contain chlorophyll plus a blue pigment. The nuclear material is not visible and they have a tendency to produce a jelly-like matrix, in which the cells become imbedded. They occur in both salt and fresh water, and can grow at relatively high temperatures. In the hot-water pools of the geyser fields of the Yellowstone Park have been found colonies of these Algae. They are found most frequently, however, in foul water in which organic decay is going on. There is little differentiation among them.

(*b*) **Green Algae. Chlorophyceae.**—In these there is no other pigment associated with the chlorophyll. The nucleus is well defined. The chlorophyll occurs in bodies called chromatophores. They show the beginning of complicated methods of reproduction.

Fig. 11.—Pleurococcus.

1. *Pleurococcus.* (Fig. 11.)—This is a very simple single-celled form of plant. Masses of these cells form a green coating on the damp trunks of some trees. There is one chlorophyll body in the cell and reproduction is by fission, i.e., one cell divides into two daughter cells. These may cling together and so clumps of cells be observed.

2. *Spirogyra.* (Fig. 12.)—This filamentous green Alga is splendid material for obtaining a good idea of a plant cell. The cells are comparatively large and cylindrical in shape. If living Spirogyra is studied a distinct green band-like chromatophore is seen to run spirally around the inside of the cell wall. In it are small bodies at intervals. These are the pyrenoids, and around them starch forms. Some species may contain more than one spiral band. Examination of specially prepared material reveals the nucleus in the center of the cell. It is surrounded by a small mass of cytoplasm from which fine strings of protoplasm run out to the thin layer of protoplasm which lines the cell wall. The remaining space is filled with cell sap.

Reproduction is peculiar. (1) Any cell may divide and make the filament longer. This is vegetative reproduction. (2) When two filaments lie side by side, two adjacent cells coming in contact may develop small tubes (Fig. 13), which form a canal connecting one cell with the other. The entire contents of one (male gamete) cell pass across through this canal to the protoplasm of the other (female gamete) cell and fusion takes place. Specimens are found in which nearly every cell of one filament has emptied its contents over into cells in the other filament with which it is connected. It is now believed that the cells moving across to the cells of the other filament are male, while the stationary cells are females. The two fused cells form a single zygote (Fig. 14), with a thick wall. In this condition the winter or some other unfavorable period is passed. When conditions are right the original walls decay and each of the zygotes develops eventually into a new filament. It should

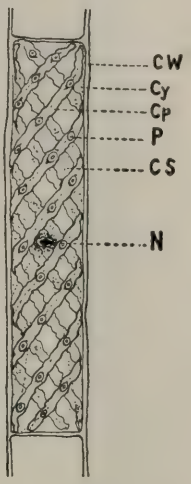

FIG. 12.—CELL OF SPIROGYRA.

CW, Cell wall; *Cy*, Cytoplasm; *Cp*, Chromatophore; *P*, Pyrenoid; *CS*, Strand of protoplasm; *N*, Nucleus.

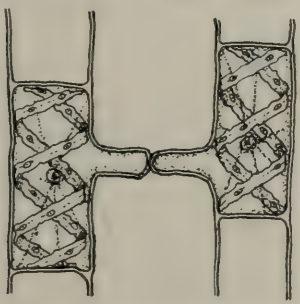

FIG. 13.—TWO CELLS OF SPIROGYRA FORMING A CONJUGATION TUBE.

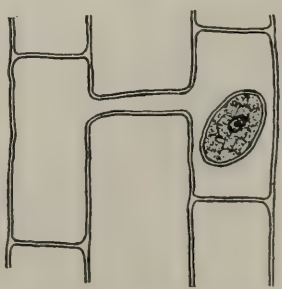

FIG. 14.—ZYGOTE OF SPIROGYRA FORMED BY UNION OF TWO CELLS.

be noted that such new filaments began life as a single cell formed by the *fusion* of two cells.

3. *Ulothrix.* (Fig. 15.)—This is a filamentous form. The cells are cylindrical and sometimes about as long as they are broad, or they may be somewhat longer or shorter than this. Inside is a thick cylindrical chlorophyll body or chromatophore. The holdfast cell at the basal end of the filament is attached to some object in the water. Ulothrix has three methods of reproduction. In the first place it may reproduce like Nostoc or Oscillatoria. Any cell in a filament may divide in two and if a filament breaks, new filaments may be formed. This is *Vegetative Reproduction.* Again a cell will divide internally a number of times (Fig. 16*a*) until the cell contains 2, 4, 8, etc., small cells. From each of these, four flagella or swimming organs develop. When mature the cell wall ruptures and these small flagellated cells swarm forth. After swimming around in the water, each settles to the bottom and by cell division forms a new filament. These small cells, produced by a sort of continued internal cell division, are called spores. Each is a small part of the original cell and each has a nucleus and each is capable of developing into a new plant. Since they swim about actively they are called *Zoöspores.* There is a distinct resemblance between reproduction by spores and reproduction by simple fission. But Ulothrix reproduces also in a third way. Any cell may divide internally into two cells and these divide again and again, as in the formation of Zoöspores, but each of these tiny cells (Fig. 16*b*) develops only two swimming flagella, instead of four, as in the case of the zoöspores. When mature the cell wall ruptures and the little bi-flagellate cells swarm forth into the water. Now if they merely swim around, they will

FIG. 15.—ULOTHRIX.

FIG. 16.–ULOTHRIX.

a, Formation of Zoöspores; *b*, Formation of Isogametes and union of same.

shortly come to rest and disintegrate. But if in their swimming one happens to meet another swimming cell, the two will then fuse together and there will be formed something like a zoöspore. This larger cell, now with four flagella is a union of two small cells and is called a *zygote*, which means " formed by union." The bi-flagellate swimming cells are called *Gametes* (from the Greek word " to marry "). Eventually by their union a new colony results. Since these little gametes are about alike in size they are called *Isogametes*. Here we are on the threshold of sexual reproduction. We see the resemblances between this new mode of reproduction and those hitherto mentioned, and also note in what respects this new method differs from the old. We do not know that one gamete fuses with gametes from the same or different cells or filaments. There is a chance that foreign gametes may meet.

4. *Oedogonium.* (Fig. 17).—This is also a filamentous alga found in fresh water ponds. One end of the filament is attached to stalks of grass or other objects in the water. The cells are long and cylindrical. It has three methods of reproduction: (*a*) Vegetative, i.e., any cell may divide into two cells, thus making for longer filaments or new filaments from broken off pieces. (*b*) Asexual, i.e., certain cells may assume an oval shape with a cluster of swimming organs or cilia at the small end (Fig. (17*b*). They are quite large and escape as a motile spore or zoöspore. Each swims about for a time, settles to the bottom, and develops into a new filament. (*c*) Sexual, i.e., by gametes. Certain cells increase in size. In them are produced more protoplasm and chloroplasts than in the ordinary cells. These large cells are spherical. They may be called egg cells (Fig. 17*c*), or female gametes or megagametes since they are relatively so large. In certain other cells of a filament internal division occurs (Fig. 17*d*), followed by the development of a few small cells, provided with cilia. (Fig. 17*e*.) These are *microgametes*. They escape from the cell in which they are formed and swim about actively. Finally one enters an egg and the two (microgamete and megagamete) unite, forming a zygote. We also call these small

actively swimming cells, sperm. The union between sperm and egg is called *fertilization*. Since these two gametes are of unequal size and shape, they are known as heterogametes, and when a new individual results or develops from the fusion of these two we call this type of reproduction sexual. The reproductive cells or gametes may be formed in any cell and there is no apparent part of the filament set apart for the production of sex cells. Moreover, both types of sex cells are produced in the same filament and this condition is known as *hermaphroditism*. Although the two gametes differ in many respects, yet they agree in that each possesses a nucleus, and there is probably a positive attraction between the male and female cell, i.e., the egg and sperm, so that the chances of fertilization are probably greater than in the case of the isogametes of Ulothrix. This is our introduction to specialization of cells for the function of reproduction. The cell which produces the sperm cells or male gametes is called an *Antheridium* because it is the place where sperm are produced. The cell which develops into an egg is called an *Oögonium* or place where an egg is produced. We can hardly call them sex organs. If we do so, it must be remembered that they are only single-celled sex organs.

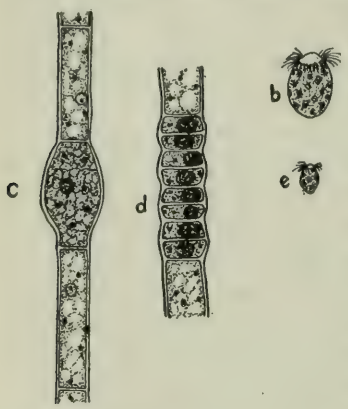

FIG. 17.—OEDOGONIUM.

Part of a filament; *b*, Zoöspore; *c*, Egg cell or megagamete; *d*, Sperm cell forming; *e*, Sperm cell or microgamete. (*b* and *e* after Strasburger.)

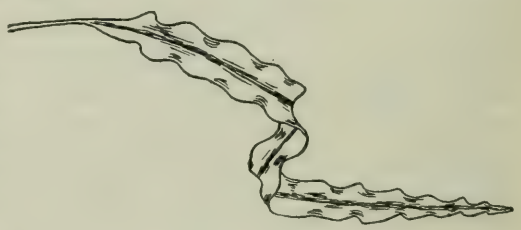

FIG. 18.—LAMINARIA.

(*c*) **Brown Algae. Phaeophyceae.**—These are usually brown in color. This is due to the presence of a brown pigment, which masks the green chlorophyll. They are almost entirely restricted to sea water and are usually attached to rocks between tide levels. The waves beat against them and at low tide they are exposed to the air. Some brown algae (Fig. 18) are the largest simple plants known. One species of *Laminaria*, a kelp, is sometimes two hundred feet in length. Kelps have a holdfast, a root-like organ which is really no root at all. They also have a stem-like trunk and a long leaf-like blade.

Fig. 19.—Fucus.
(Photo by Fread.)

Some species of brown algae exhibit organs of reproduction of an advanced type. *Ectocarpus* is a filamentous form. It consists of branching filaments of linearly arranged cells. Certain cells divide internally into numerous regularly arranged compartments of many cells. In each of these is developed a gamete with two motile cilia. In other words, we have these gametes produced in a special organ known as a *plurilocular gametangium*. The gametes may differ in size, indicating an approach toward the egg and sperm condition. A new plant develops from the cell formed by the fusion of two gametes. Other special cells in another filament form zoöspores from a single cell called a *sporangium*. Thus a simple type of sexual and an asexual method of reproduction are presented. The one filament contains both *sporangia* and *gametangia*.

A second example is *Fucus* or rockweed (Fig. 19). Fucus has a holdfast and many strap-shaped branches. These branches fork in twos and a dark line of more densely arranged cells is found in the middle of each branch. Bladders (Fig. 20*a*) filled with gas produced by the plant, occur here and there, buoying up the branches in the water. The ends of some branches have swollen tips or receptacles (Fig. 20*b*) covered with warty extensions. There is a small pore at the outer end of each of these swollen points. Each pore opens into a cavity or conceptacle (Fig. 21, Fig. 22*a*), whose walls are lined with a mass of hair-like filaments of linearly arranged cells, the paraphyses. Attached to some of these are little club-shaped bodies, the *Antheridia* (Fig. 22*b*). In them biciliate cells, the sperm, are produced. In the same (or in some species in separate conceptacles) are found larger oval-shaped bodies attached to the wall by a short stalk of a few cells. These are the *oögonia* (Fig. 22*c*). Each oögonium produces eight eggs. When mature these escape to be fertilized by the motile sperm (Fig. 22*d*). If one plant produces sperm only it is a male plant, another producing eggs only is a female plant. The condition in which the sexes are separate is known as

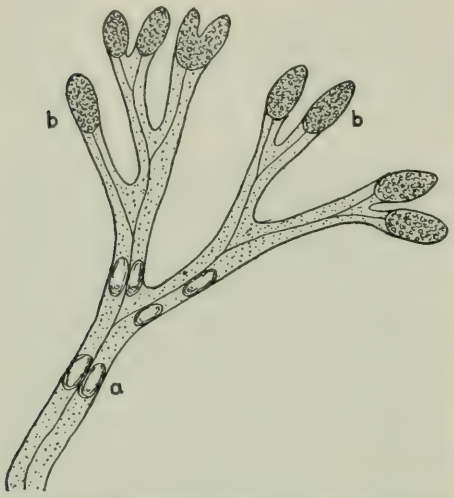

FIG. 20.—FUCUS, SHOWING BRANCHING HABIT OF PLANT BODY.

a, Bladder; *b*, Receptacle.

FIG. 21.—SECTION THROUGH RECEPTACLE OF FUCUS SHOWING EIGHT OÖGONIAL CONCEPTACLES.

Dioecious. When both sexes are united in the same organism, the species is *Monoecious*. Fertilized eggs develop into new Fucus plants. Fertilization occurs in the sea water outside the plant. Fucus produces no zoöspores.

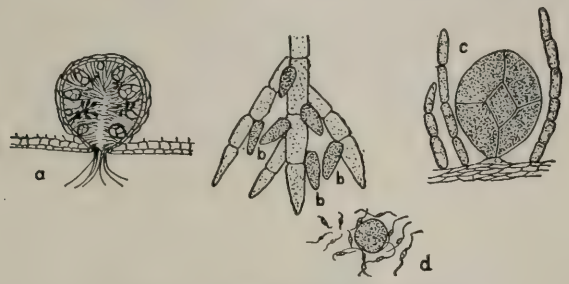

FIG. 22.—REPRODUCTION IN FUCUS.

a, Larger view of conceptacle; *b*, Six antheridia; *c*, Oögonium; *d*, Egg surrounded by sperm. (From Sinnott's Botany, after Thuret.)

(*d*) **Red Algae. Rhodophyceae.**—These have delicate feathery branches for the most part and generally grow in salt water. They are better represented in warmer waters than are the brown algae. One form, *Chondrus crispus* (Fig. 23) or Irish moss, when dried, is used in the preparation of gelatin. Other types of red Algae produce *Agar-Agar*, extensively used as medium in which cultures of bacteria are grown.

FIG. 23.—CHONDRUS CRISPUS—IRISH MOSS, A RED ALGA.

(*e*) **Desmids and Diatoms.**—*Desmids* are unicellular plants with green chromatophores and live in fresh water near the edges or bottom of ponds. The cell has two symmetrical halves. The zone between the two halves is frequently constricted and here the division takes place, resulting in the formation of two cells. This is the method of reproduction. Desmids possess some power of locomotion. There are about 1000 species

and a great variety of form. The cell walls are also elaborately marked. (Fig. 24.)

Diatoms are also single-celled plants, and possess great variety of form and markings. The cell wall of diatoms is impregnated with silica. A number of individuals may unite side by side forming long zigzag chains or filaments of cells. There is chlorophyll present and also a yellow-brown pigment. Diatoms appear on the surface of the water where the conditions favor their increase. Fishes feed upon them. On the cell wall are regular patterns of raised dots or lines or other forms of markings. These dots, lines, etc., may be depressions in the shell also. Some diatoms serve as useful test objects for determining the power of microscopic lenses. As floating diatoms die, the empty shells sink to the bottom. Here the skeletons may accumulate. Fossil deposits of these shells are sometimes found. When these deposits are of great thickness they indicate the presence of lakes or oceans in such localities in ages long past. From such deposits "Fossil Flour" or "diatomaceous earth" are derived. This is an ingredient in some polishing powders. Desmids and diatoms are usually classified with the Green Algae.

FIG. 24.—LEFT, A DESMID; RIGHT, DIATOMS.

Summary of Algae.—The Algae are aquatic plants of distinctly simple organization. Beginning with those forms which are single cells, they develop into linear associations of cells which are more complicated by branching filaments as in *Ectocarpus*. *Ulva*, a green alga, forms large broad sheets which are very thin. In the Brown and Red Algae associations of cells in three directions form smaller or larger masses of quite similar cells, and especially large masses in the Brown Algae. We have, as it were, seen a progressive evolution from single points to lines, to surfaces, to masses. As far as the plant body is concerned, it never becomes complex. There are no special

organs for metabolic functions such as circulation of plant fluids. They have, however, specialization for reproduction.

The Algae are the most ancient of true plants that have chlorophyll. Of all the four groups, the botanists are agreed that the green algae must be regarded as that group which was ancestral to the next group of higher plants known as the *Bryophytes*.

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CHAPTER V

PHYLUM I. SUB-PHYLUM II. FUNGI

The Fungi are Thallophytes that cannot make carbohydrate from carbon dioxide and water; they possess no chlorophyll and are dependent plants. There are, however, groups of very simple plants that belong neither to the Algae nor to the Fungi, and whose position in plant classification is still uncertain. The *Bacteria* form one of these groups.

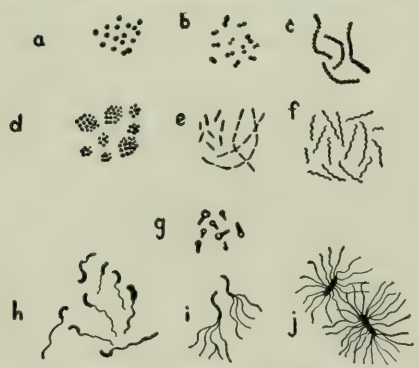

FIG. 25.—TYPES OF BACTERIA.

a, Coccus; *b*, Diplococcus; *c*, Streptococcus; *d*, Cocci from pus; *e*, Bacillus; *f*, Spirilla; *g*, Polar spores; *h*, *i*, *j*, Three types of bacteria with flagella, i.e., organs of locomotion.

1. The Bacteria.—These are the very smallest known organisms and indeed the simplest. High powers of microscopic magnification are needed to make them visible, and even then, some which are known to exist because of their influence cannot even be seen. Three types of form are found (Fig. 25), (1) the *Coccus*, which is a spherical cell. *Pneumococcus*, the organism which causes pneumonia, belongs to this general group. Cocci may be arranged in rows, in which case they are called *Streptococci*, as in the organisms which cause septic sore throat, blood-poisoning and possibly tonsilitis. (2) The *Bacillus* is rod shaped. The bacillus typhosus and tuberculosis are examples of this type. (3) The *Spirillum* is shaped like a corkscrew, the number of revolutions varying from one to many. Organ-

isms which cause cholera have this form. The student should not conclude that all bacteria are disease-producing, for many occur normally in the human intestine, performing a useful function. Attention is later called to the great usefulness of soil bacteria. Bacteria possess no distinct nucleus, but it is believed that nuclear material is distributed throughout the protoplasm. Some have little protoplasmic motile processes called *cilia*, by the movement of which they possess considerable power of locomotion. Some have a single flagellum at one end. Cholera bacteria move in water at the rate of 15 mm. an hour. Bacteria reproduce by simple *fission*, i.e., the bacterium divides in two and each daughter cell soon grows to a mature size and is then ready for reproduction again. So rapid is the reproduction at times that millions may be formed from one original cell in the course of a single day. Certain organisms are able to surround themselves with a sticky gelatinous matrix, forming a capsule which they secrete. Such a formation is known as *Zoögloea*, as "Mother of Vinegar." Under unfavorable conditions some bacteria go into a resting stage called a *spore* in which the organism is surrounded by a very thick wall. In this state the cells resist death from desiccation or other adverse conditions for many years. When proper conditions return the spore wall bursts and the living cell escapes, feeds and reproduces, thus recolonizing the medium in which it lives. Bacteria live practically everywhere, in water, in deserts, in air, in soil, in hot springs, in ice, in milk and in the bodies of plants and animals. They concern civilized life to such an extent that the separate biological science of Bacteriology has come to be one of the greatest importance.

In studying them the bacteriologist determines first their morphology, which is the smallest part of his task. He also studies the form, color and structure of their colonies grown on various types of nutritive media, such as gelatin and agar-agar. The physical and chemical changes produced by these colonies in the media are important criteria of identification. Some species are so small that they cannot be studied microscopically except by the

methods just indicated. Such types pass through ordinary bacteria-proof filters. Rabies and smallpox are caused by such organisms and are known as "filterable viruses." It is an almost universal characteristic of living things that they use atmospheric oxygen in their metabolic activities. There are bacteria, however, that exist in the absence of atmospheric oxygen. These are known as *anaerobic bacteria* to distinguish them from the great majority of air-loving forms which are called *aerobic.* Special cultural methods are used for the cultivation of such forms. Indeed, anaerobic bacteria perish if exposed to the atmosphere.

Some kinds of bacteria are *parasitic,* i.e., they inhabit and obtain their food from living organisms. They are not necessarily harmful. Many kinds of such harmless bacteria are always found in the intestinal tract of animals. *Saprophytic bacteria* live on dead organisms and play an important rôle in the cycle of organic life. By means of ferments or enzymes they break down, step by step, the complex proteins of the organisms into simpler compounds of putrefaction so evident by their offensive odors. They form ammonia. Carbohydrates and fats are disintegrated into carbon dioxide and water. The classes of bacteria that bring about decay are of vital importance to the existence of plant and animal life. These bacteria free chemical elements for further use in new generations of animals and plants. They have been called the traffic policemen of the elements, keeping them in circulation, now forming substance of living things and later being part of the inorganic world to be built later into living tissues again. The carbon dioxide formed in processes of decay is returned to the atmosphere and may again be used by green plants in the manufacture of carbohydrates. A certain group of bacteria, *Nitrosomonas,* converts the ammonia above referred to into nitrites. Some of these nitrifying bacteria can even use carbon dioxide in the absence of chlorophyll.

Some biologists have speculated as to the earliest formation of living things in the comparatively early days of the Earth. They have suggested that forms similar to Nitrosomonas might have been the first living things. *Nitro-*

bacter is a bacterium which can change nitrites into nitrates and thus such salts as potassium and calcium nitrates may be formed which are taken up by the roots of plants and from such compounds the nitrogen of proteins may be obtained. Certain nitrogen-fixing bacteria live on roots. They are able to utilize the free nitrogen of the air and form compounds which are used by those plants with which the nitrogen-fixing bacteria are associated. Other bacteria decompose organic compounds containing sulphur, iron and phosphorus, and so bring about compounds of these elements which can be utilized by living plants.

It is generally known that some bacteria cause disease. These are known as *pathogenic bacteria.* They destroy tissues directly or secrete toxins or poisons which prevent normal physiological function. Pneumonia, typhoid fever, tuberculosis, diphtheria, rabies, cholera, and bubonic plague are caused by pathogenic bacteria.

The bacteria resemble the Cyanophyceae in some respects. Reproduction in both groups is by fission. Both types of organisms produce a jelly-like matrix. In neither is there a well-defined nucleus. Some biologists, on account of these resemblances, group bacteria and cyanophyceae into the group *Schizophytes*, i.e., plants that reproduce by fission. However, blue-green Algae possess chlorophyll, in spite of the fact that this is masked by a blue pigment, *phyocyanin.* The presence of chlorophyll makes it possible for these algae to manufacture carbohydrates from carbon dioxide and water. This, the bacteria, as a whole, cannot do. They must have already prepared carbohydrates to feed upon. In other respects bacteria resemble still other groups of organisms.

2. **Myxomycetes.**—This is a group of simple organisms of somewhat uncertain position, which are usually considered with plants. Some taxonomists regard them as simple animals and call them *Mycetozoa.* The common name is *slime molds.* The organism consists of a mass of naked slimy protoplasm which has a creeping motion. Tongue-like processes are put forth and extend in a certain direction. The protoplasmic mass at the other end draws up in the

direction of the movement. They live on decaying wood or dead leaves in dark, damp places. There is no chlorophyll present and they are therefore dependent. They are sensitive to light and appear in dark places. In the protoplasmic mass are found distributed nuclei. The entire mass is a colony of cells without cell walls. Such an association of cells without separating walls is called a *Coenocyte.* The organism feeds on bacteria and other small organisms. It simply engulfs its food. At times the superficial protoplasm forms a hard external layer enclosing a thickened protoplasmic mass within. In this resting state it may remain for years, but will resume its normal activity when proper external conditions return. The method of reproduction is more plant-like than animal-like. In this process very small spherical single-celled bodies are formed. These are *spores.* When the spores are mature, the sporangium, or spore case, in which they were formed, becomes dry, bursts and the spore cells are discharged. From the spore a single irregular-shaped cell escapes. This cell develops a *cilium* or *flagellum.* It moves about. In this stage it resembles protozoa or single-celled animals. It may divide by fission many times, producing many similar cells. At a later period the cilia disappear. Many such irregular-shaped cells come together. In this way a new protoplasmic mass, similar to the parent organism, is formed again. The body of the organism is called a *plasmodium.* In food habits, Myxomycetes resemble animals. In the ciliated motile stage, as well as in the single-celled ameboid like stage, they also are quite animal-like. But in the production of spores, they are like plants and especially like the Fungi. When one considers all the characteristics of simple forms like the Myxomycetes, one feels that, after all, it is quite difficult to decide as to just what an animal or plant is. When we think of plants and animals we usually think of the higher plants and the higher animals between which there are many apparent differences. Consideration of these lowly organisms, on the other hand, serves to emphasize the underlying unity of organic nature.

3. THE FUNGI

This great group of Thallophytes is composed of forms which contain no chlorophyll. They cannot make carbohydrates and are therefore dependent. They may be *parasitic* or *saprophytic*. The plant body is called a *mycelium*. It is composed of a mass of filaments called *hyphae*. The mycelium is connected with dead or living organic matter; in some cases by special absorbing root-like structures called haustoria. Upright branches produce spores and may therefore be called *sporophores*. The sporophores are usually brought well above the surface of the host so as to favor distribution of spores. Enormous numbers of spores are produced. They are present in the atmosphere almost everywhere. Some fungi have well-defined sexual reproduction as well as asexual reproduction by spores. Three large groups are found in nature. These are (*a*) the *Phycomycetes* or alga-like fungi; (*b*) the *Ascomycetes* or sac-fungi, and (*c*) the *Basidiomycetes* or basidial fungi.

(*a*) **The Phycomycetes.**—The Phycomycetes resemble Algae that have lost their chlorophyll. There are no walls to separate the cells of the mycelium. Such an arrangement is called a *coenocyte*. They produce *isogametes* in some forms and *heterogametes* in others.

1. *Saprolegnia* is a water mold found on the dead bodies of fishes, cray-fish and water insects. One species often causes great destruction of the eggs and young fry in fish hatcheries.

2. *Albugo* (Fig. 26) is a mold which grows in leaves or flowers of mustard plants. The mycelium grows into cell spaces of the host forming a ramifying network. The spore-producing organs form clusters under the epidermis separating this from the tissue underneath. Thus the epidermis becomes broken. Spores are formed one after the other by constrictions of the end of the sporophore. They form in rows. Spores produced in this way are called *conidia*. Each conidium contains many nuclei. A leaf infected with sporophores presents the appearance of a white blister. The fungus is, therefore, commonly known as

white rust or *blister blight.* The spores are scattered by wind. They germinate on the surface of wet leaves and form zoöspores which move over the leaf, rest and send hyphae through the air pores in the epidermis of the leaf, thus infecting it. This form possesses sexual reproduction also. *Potato blight* or *rot* and *grape blight* are other examples of this type of mold.

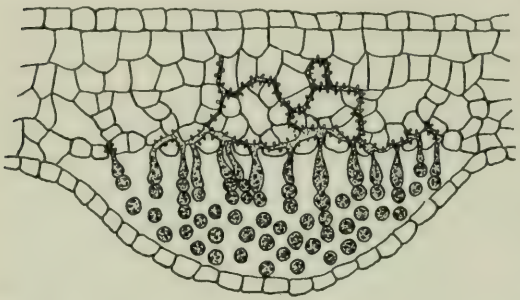

FIG. 26.—ALBUGO OR BLISTER BLIGHT—WHITE RUST.

Section through a blister, showing elevated epidermis of the leaf; the mycelium of the fungus ramifying between the cells of the leaf. Inside the blister are sporophores and spores.

3. *Rhizopus* (Fig. 27) is the common black mold which grows on bread. Damp bread, kept under a glass jar, will exhibit a luxurious growth of black mold in a few days. The spores are in the air everywhere. The mycelium is coenocytic. The branching hyphae present a woolly appearance. Long vertical stalks end in round black sporangia in which a great number of spores are produced. This black mold possesses a sexual method of reproduction also. Two nearby hyphae come together side by side.

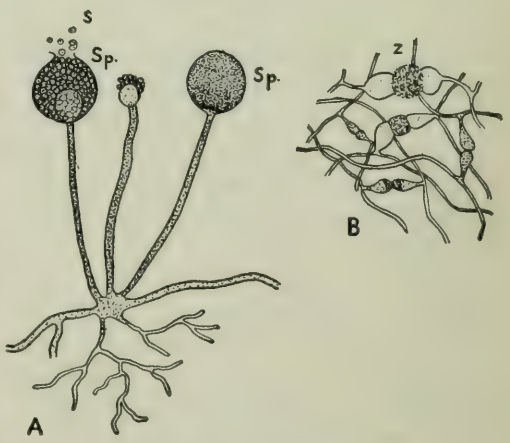

FIG. 27.—RHIZOPUS.

A, Mycelium with branching hypae; *Sp*, Sporophore hyphae with sporangia at ends; *s*, spores; *B*, Stages in sexual method of reproduction; *Z*, Zygospore.

Short side branches from each grow toward the other. The ends unite. The united part becomes separated from the two hyphae by cross partitions. A cell, or zygote spore is thus formed by the conjugation of the two gametes. The zygote spore develops a thick wall. After a time it germinates, forming a small mycelium, with a sporangiophore and sporangia. Of the two gametes which fuse to form a zygote, one comes from a male and the other from a female mycelium.

The Phycomycetes resemble the green Algae in the formation of oöspores and zygospores.

(*b*) **The Ascomycetes.**—Most of the Fungi belong to this group and the next. There are about 20,000 species. The mycelium consists of filaments in which the cells are separated from one another by walls. The sex organs are reduced or absent. The characteristic of this group is the possession of the *ascus* or sac in which the spores (ascospores) are produced.

1. *Yeasts* (Fig. 28) are simple Ascomycetes. They are simple microscopic plants and there are about fifty varieties. The form used in bread making is called *Saccharomyces cerevisiae*. It consists of ovoid-shaped colorless cells with a nucleus and a sap cavity in the cytoplasm. The cells feed on sugar solution. The products of their metabolism are carbon dioxide and alcohol. The carbon dioxide "raises" the bread dough. Yeast can reproduce by forming a bud. This remains attached to the parent cell and grows. The bud cell may also form a bud. Chains of yeast cells are thus formed. Yeast also forms spores. If the food is scanty the cell divides twice, forming a sac (ascus) with four spores. The wall is hard and resistant. Later, when favorable conditions return, the wall ruptures, releasing the spores. These are driven about by wind and may reach favorable soil. Yeasts are employed in the manufacture of wines and beer. The yeast cell contains an enzyme which changes sugar (glucose) to carbon dioxide and alcohol.

FIG. 28.—YEAST CELLS.

The formula is $C_6H_{12}O_6 = 2CO_2 + 2(C_2H_6O)$. This is ordinarily called *fermentation*. When the alcohol formed increases to about a 15 per cent solution, the growth of the yeast ceases. Stronger solutions of alcohol are obtained by distillation. To ensure specific and regular results, special yeasts are cultivated. In bread making great care is taken to avoid contamination with wild yeasts.

2. *Ergot* (Fig. 29).—(*Claviceps*) is a fungus disease in rye. Rye infected with ergot is unfit for use. Extract of ergot is a powerful drug and causes contraction of muscle. It is used in medicine to contract the muscle of blood vessels and arrest hemorrhages. The fungus consumes the ovary of the rye grain, replaces it with a mycelium and forms a hard compact mass-ergot. A head of rye may contain a number of infected grains among the normal grains. Rye bread made from infected rye flour has been known to be the cause of widespread food poisoning.

FIG. 29.—HEAD OF RYE INFECTED WITH ERGOT.

3. *Endothia* is another example of an Ascomycete. This is chestnut blight. It was probably introduced into this country with foreign chestnut trees. Once introduced, it attacked our native chestnuts and within a few years has destroyed almost all of them. There is no known means of checking the spread of this disease. The spores driven about by the wind get into the crevices in the bark of the tree. There they germinate, producing a mycelium which grows deep into the wood where it cannot be destroyed. Endothia also lives on oaks, but does not harm them much.

4. *Aspergillus* (Fig. 30*a*) is a common blue-green mold. Its delicate mycelium spreads in and over the substratum and sends up long conidiophores at the upper end of which long lines of radiating conidia are produced.

5. *Blue mold, Penicillium* (Fig. 30*b*), common on moldy bread, is another example. It is this mold which gives the flavor to Roquefort cheese.

Black Knot which appears as a black enlargement on the

branches of cherry and plum trees; *Truffles*, a tuberous like edible fungus, used largely in Italy and France; and the *Morel* (Morchella), another edible fungus, are also examples of Ascomycetes.

The Lichens (Fig. 31) comprise a unique group. They are the familiar grayish dry growth on old fences, trees or rocks and are composed of an Ascomycete in the mycelium of which live simple green or blue-green Algae somewhat like Pleurococcus. This association of two kinds of organisms is called *symbiosis*. Litmus, used to test the alkalinity or acidity of solutions, is derived from a lichen. Iceland moss, a lichen, is used as food by natives of northern countries.

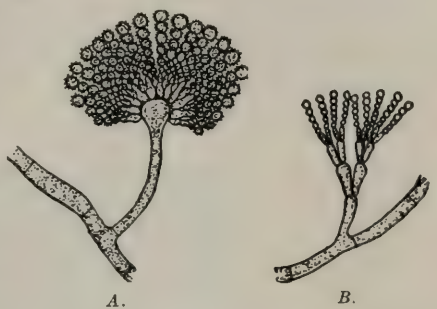

FIG. 30.—*A*, ASPERGILLUS; *B*, PENICILIUM. Sporophore with characteristic formation of conidia.

(*c*) **Basidiomycetes.**—Some of these are the most destructive of crop parasites. They are the smuts and rusts, also toadstools and puff balls. Basidiomycetes are larger than Ascomycetes. The spore-producing organs are more prominent. The distinctive feature explaining the name is the *basidium*. This is the swollen end cell of a hypha. Each basidium usually bears four cells or basidiospores. The basidium corresponds to the ascus. The basidia are collected in large parallel groups, forming a special spore-producing region called the *hymenium*. There is rarely any sexual reproduction. There are more than two thousand kinds of smuts.

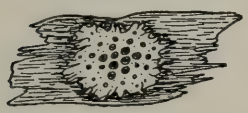

FIG. 31.—PHYSCIA—A LICHEN ON WOOD.

1. *Corn smut* is very common and very destructive. The spores of this fungus, *Ustilago*, are carried from one corn plant to others by the wind. The spores produce a mycelium which penetrates the newly infected plant. This develops

especially well in the ovaries of the young corn flower, forming the smut. Thus the seed is destroyed. They may also attack the stamens. Great numbers of resting spores are formed. These are scattered and rest over the winter. In the next spring they will germinate on manure or other decaying organic matter. The mycelium from this growth also forms spores which will probably infect the new stand of corn, or the new seed in the ground or the young plants. Thus one stage in the life history is parasitic on the corn plant and the other is saprophytic on organic matter in the soil.

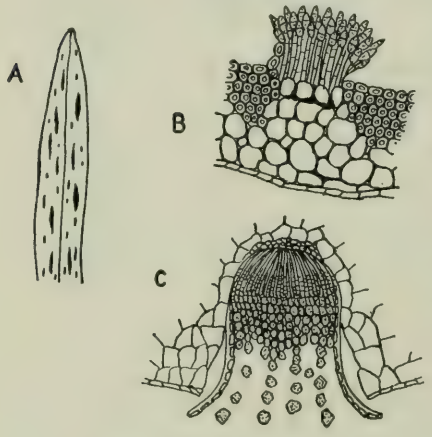

FIG. 32.—PUCCINIA.

A, Leaf of wheat infected with rust. Dark patches are masses of summer spores (Uredospores); *B*. Cluster of teleutospores (winter spores); *C*, Cluster cup or Aecidium in lower part of leaf of Barberry plant forming Aecidiospores.

2. *Puccinia* (Fig. 32) is Wheat Rust. It is very destructive. A mycelium is formed in the body of the plant. The spore masses present a rusty appearance, hence the name. Wheat rust has a complex life history in which there are three types of spores, Uredospores, Teleutospores and Aecidiospores. In Puccinia graminis, there is an intermediate host, the American barberry in which Aecidiospores are produced. It has been found that the buttercup, spruce, apple and some other plants act as hosts to the aecidium stage. It has also been determined that uredospores may retain their vitality over the winter and infect spring wheat directly.

3. There has recently appeared the *white pine blister rust*, accidentally introduced from Europe. This may destroy all our white pine timber before it runs its course. Certain plants as the gooseberry are secondary hosts. It may be necessary to destroy these to save our native pines.

4. *Mushrooms* constitute another group of Basidiomycetes (Fig. 33). They form an extensive mycelium in dead organic matter (saprophytic), and a large umbrella-shaped sporophore is developed above the ground. On the under side of the sporophore (more protected) is the spore-producing tissue, the hymenium with basidia-producing basidiospores. A familiar type is *Agaricus campestris*, the edible field mushroom, which is extensively cultivated for the market. Rounded masses of hyphal tissue develop in the humus. In these, sporophores develop and break

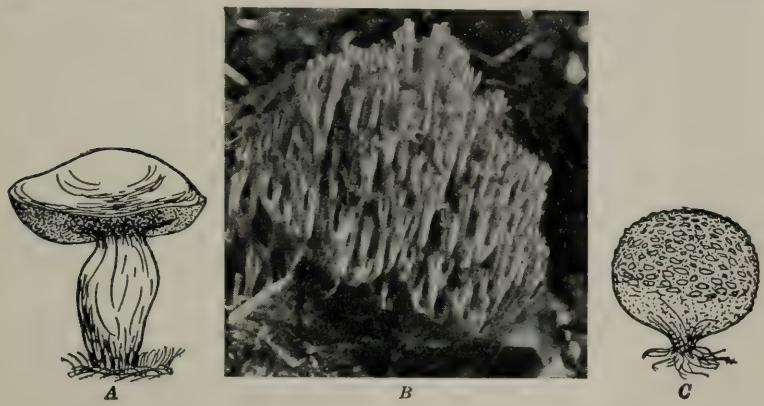

FIG. 33.

A, Boletus, a mushroom type in which spores are formed in tubes ending in pores on under surface; *B*, Coral fungus; *C*, Puff ball. When mature multitudes of spores are found in the interior.

away from the rounded masses and grow up, forming the stalk and umbrella-like cap, the pileus. On the under side of the pileus are radiating gills or plates of hyphal threads. These gills bear the tissue which produces the basidia. Many poisonous forms occur among the gilled fungi. Amateurs should study the subject carefully in order to be able to recognize edible mushrooms from non-edible. In some varieties tooth-like projections on the under side of the pileus bear the spore-producing tissue. These are the *tooth fungi*. Another type is the *pore fungi*, where this tissue is borne on the inner walls of little canals. In the *bracket fungi* the mycelium ramifies through the tree trunk,

destroying it and the sporophore is a bracket on the surface of the trunk. In *coral fungi*, the sporophores form a cluster of branches. *Puff balls* possess lobular sporophores which remain closed until spores are ripe. One type is an enormous ball eighteen inches in diameter. Most puff balls are edible.

Summary of Fungi.—Some botanists relate the Ascomycetes and Basidiomycetes to the Phycomycetes and others to the red Algae. It is also said that the Basidiomycetes were derived from the Ascomycetes. There are about 40,000 Ascomycetes and Basidiomycetes. Indeed, there are probably more Fungi than Algae. It is commonly assumed that all the Fungi are degenerate Algae. This great group, however, seems to have been wonderfully successful and may have developed contemporaneously with the Algae.

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CHAPTER VI

PHYLUM II. BRYOPHYTA

Definition.—The second great phylum of plants is known as the *Bryophyta*. They are comparatively few in number, having only 16,000 known species, while there are 60,000 species of Thallophytes known. The Bryophytes are all small forms. They are especially interesting because they are the living descendants of the first plants which emerged from an aquatic mode of life to a terrestrial existence. They have sprung from the Algae and one group shows many alga-like characteristics. The Bryophyta are divided into the *Hepaticae* or Liverworts, and the *Musci* or Mosses.

I. **Hepaticae.** (*a*) *Riccia* (Fig. 34).—This is a small green plant, quite alga-like, in appearance. The body is flat and leaf-like and hence is called a thallus. As the thallus grows it or forms two lobes with rounded ends. On the under side are hair-like processes or rhizoids, resembling simple roots. Sometimes Riccia is found floating on the surface of a pond, in which case it possesses no rhizoids. It develops these when the pond dries up and the former floating plants settle to the bottom. Male sex organs or antheridia occur on the upper surface in grooves which are found in the center of the thallus. Inside the antheridia, ciliated or flagellated sperm are produced. The female sex organs or archegonia also grow up from these grooves. Each archegonium is a flask-shaped structure with a wall consisting of one layer of cells. It has a long outer neck and an enlarged oval base or venter. The neck has a neck canal and in the venter is a single large egg cell or ovum. Sperm pass down the neck and one of them fertilizes the egg.

Fig. 34.—Riccia.

The sperm and eggs remind us of those found in the Algae. But Riccia, in addition, has definite sex organs. After fertilization, the fertilized egg undergoes many cell divisions. This multicellular structure never attains any great size. It becomes a sac in which spores are developed and hence the sac-like structure is called a sporophyte or spore-producing plant. It is really not a separate plant, but rather a structure which is parasitic on the Riccia thallus and remains long enough to produce and discharge the spores. The discharged spores may grow into new Riccia thalli. Sperm and eggs are *gametes* and since the Riccia thallus reproduces by means of its sex organs, it is called a *Gametophyte.* The fertilized egg develops into the small *Sporophyte* which produces spores and this is called a new generation. All that the Riccia thallus can do is to produce gametes. The thallus, however, develops only from spores which are produced by the small sporophyte. The gametophyte generation is sexual, the sporophyte generation is asexual. The gametophyte plant is green and independent while the sporophyte structure is parasitic and does not possess chlorophyll. The sporophyte is also very small compared with the gametophyte. Riccia illustrates a possible transition from the aquatic Algae to the terrestrial Hepaticae or liverworts.

(*b*) *Marchantia* (Fig. 35), a little flat leaf-like plant, is a land form, living on damp soil or rocks, and it shows considerable differentiation of structure when contrasted with the Algae. On the upper surface, are many small pores, each in the center of a definite area. A study of a cross-section shows additional differentiation. (Fig. 36.) The upper surface is composed of a layer of protective cells, the *upper epidermis.* The air pores in this lead into air chambers. In these are groups or strings of cells which contain chlorophyll, which impart the green color to the plant and also enable it to make its own food and protoplasm. Below these spaces are several layers of thin-walled polygonal shaped cells in which the manufactured starch is stored and this tissue is called *parenchyma,* storage tissue. Below this is a layer of lower epidermal cells. The *rhizoids* are long

prolongations of these cells. There are also ventral scales. The air pores, air chambers and rhizoids clearly show advances over the Algae as well as definite adaptations for land conditions.

Marchantia extends its growth vegetatively. Each lobe of a thallus may grow forward and divide into two lobes and the opposite end of the original lobe dies away from the old thallus. In this way Marchantia plants may spread over a considerable area. The plant also has another asexual method of reproduction. Small cup-like bodies grow on the upper surface. These are called *cupules*. (Fig. 35.) In these are produced little flat, leaf-like bodies called *gemmae*. They are miniature thalli. Shed from the plant, they may grow into new thalli. Sexual reproduction is also present.

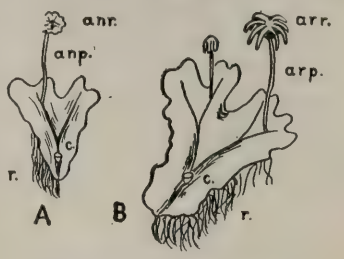

FIG. 35.—MARCHANTIA.

A, Male thallus; *B*, Female thallus; *r.*, Rhizoids; *c.*, Cupule in which gemmae are produced; *anp.*, Antheridiophore; *anr.*, Antheridial receptacle; *arp.*, Archegoniophore; *arr.*, Archegonial receptacle.

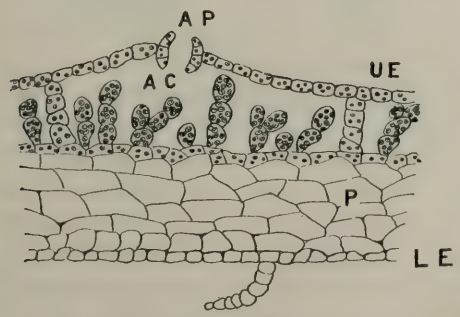

FIG. 36.—CROSS-SECTION THALLUS OF MARCHANTIA.

U. E., Upper epidermis; *A. P.*, Air pore; *A. C.*, Air chamber; Chlorophyll cells in air chambers; *P.*, Parenchyma; *L. E.*, Lower epidermis.

Arising from the central groove of some thalli are long stalks with a disk-like structure at the top. This entire organ is known as an *antheridiophore*, (Fig. 35), and the saucer-like disk above is the *antheridial receptacle*. Imbedded in this and not exposed as in Riccia are the sac-like antheridia or male sex organs (Fig. 37*A*), which produce sperm. They contain rows of cubical shaped, sperm-producing cells. The sperm are small biciliated single cells which possess the power of

active locomotion. The female sex organs resemble the male to a certain extent. A stalk is present and on the top is a disk divided into rays like a daisy. The whole structure is an *archegoniophore.* (Fig. 35.) On the underside of the upper disk-like receptacle are the *archegonia* (Fig. 37*B*), which resemble the archegonia of Riccia, each with a neck, neck canal, and a venter containing an egg. It is difficult to see how fertilization can take place unless the plants are submerged in water, since the antheridia

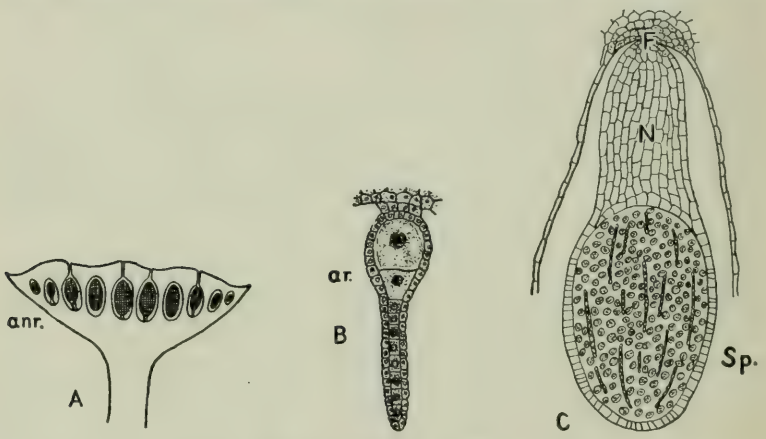

FIG. 37.—MARCHANTIA.

A, Antheridial receptacle with antheridia; *B*, Archegonium with neck and venter enclosing an egg; *C*, Sporophyte attached by *F.*, Foot to under side of archegonial receptacle; *N.*, Neck; *Sp.*, Sporangium or spore case.

and archegonia are raised so far up from the thallus. The Marchantia thallus is a gametophyte since it produces gametes of two kinds, eggs and sperm. The sexes are separate, that is, Marchantia is dioecious. As in the case of Riccia, the fertilized egg develops into a sporophyte. This many-celled structure is much larger than that of Riccia, but resembles it, in that it is small as compared with the gametophyte thallus. It is also parasitic on the gametophyte and exists just long enough to produce spores. It possesses three parts (Fig. 37*C*): (*a*) the foot, a group of cells by which the sporophyte is attached to the archegonial receptacle and by means of which the sporophyte obtains

food, (*b*) a neck or short thick stalk or seta and (*c*) the sporogonial case of the sporangium in which the spores are produced. Along with the spores are formed spirally twisted structures called *elaters*. When the spores are mature the elaters curl up somewhat like a spring and aid in the discharge of the spores. Each spore is a single-celled body which is capable of growing up into a new Marchantia thallus. Thus we have here also an alternation between a *sexual gametophyte generation* and an *asexual sporophyte generation*. The gametophyte generation is the green conspicuous and independent stage while the sporophyte generation is just the opposite. The two generations are connected. Alternation of generations is characteristic of the Bryophytes. It is present in some Algae but is not characteristic of that group. Most of the Algae that produce both spores and gametes can reproduce by either method, i.e., the two are not vitally connected in an alternation of generations. As plants become more complex, there is a progressive decrease in the size of the gametophyte and an enormous extension in size of the sporophyte.

(*c*) *Anthoceros* (Fig. 38) is a liverwort which shows a very significant development of the sporophyte. The gametophyte thallus is flat. The sporophyte is a long slender structure whose foot is deeply imbedded in the thallus. The sporangium extends for a considerable distance in the air. It is a slender cylindrical organ whose walls consist of a few layers of cells. In the center is a rod of long cells called the columella. The spores develop at the outer end first, and are discharged from the tip. The sporangium continues to split as the spores mature and are discharged. The significant thing about the sporophyte of Anthoceros is that the cells of the outer wall of the spore case develop chlorophyll and have breathing pores like the leaves of higher plants. This sporophyte can make starch, though the foot buried in the tissue of the thallus (gametophyte) still makes it parasitic. However, if it should be separated from the

Fig. 38.—Anthoceros.

gametophyte and then develop roots at the lower end it would become entirely independent of the gametophyte, as we find it in the ferns and flowering plants. Anthoceros indicates how the sporophyte of these higher plants attained independence of the gametophyte.

II. **Musci.**—These are the higher Bryophytes. They are commonly called Mosses. A moss is a real land plant, although it inhabits damp and shady places. The plant is erect and not prostrate, as is the liverwort. Its greater area of leaf surface makes possible a greater starch production. The most common group is that of the *Bryales*. They occur as beds of moss which are formed by innumerable tiny plants growing side by side. A large and well-known genus is *Polytrichum*. (Fig. 39*A*.) It has a number of common names, such as *robin's wheat moss, pigeons' wheat* and *haircap moss*. It has an upright stem around which are radially placed small leaf-like structures. The lower end is in the earth and from this buried end originate root hairs or rhizoids which absorb mineral solutions from the soil. Each plant occupies but a small ground area. But if we determined the total area of one surface of all the leaves we would find that it was many times that of the ground occupied by the plant. The amount of leaf surface determines to a large extent the amount of starch that can be made by the plant. Polytrichum has much larger area of leaf surface than ground area occupied as compared with the liverwort. In other words, Polytrichum is an advance over the liver-

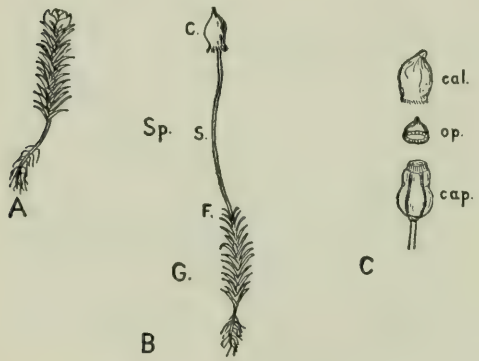

FIG. 39.—POLYTRICHUM.

A, Plant with rhizoids, stem and leaves, sex organs at tip; *B*, Gametophyte as before but with sporophyte growing at upper end. *F.*, Foot; *S.*, Seta and *C.*, Capsule of sporophyte. *C*, *cal.*, calyptra, *op.*, operculum and *cap.*, capsule of spore case.

wort. This advance consists in the upright stem and radially placed numerous leaf-like structures. The higher plants did not evolve from these higher Bryophytes. Yet the higher plants have this arrangement of leaves upon a central stem. It would not be scientifically correct to make dogmatic assertions with regard to this, but one is inclined to regard this structural plan of Polytrichum as a sort of natural experiment ending in the production of mosses with upright stem and leaves in contrast to the simple prostrate thallus of the liverworts whose amount of starch production is more directly proportional to the amount of ground area occupied.

A study of the stem (Fig. 40) shows an outer Epidermis which is a layer of protective cells; then a region of soft-walled food storage cells called the *parenchyma* and in the center a column of elongated cells which is vascular tissue. These cells transport soil water from the earth up to all parts, especially the leaves and also transport sugars down from the leaves. The leaves are more simple than the leaves of higher plants. They consist as a rule of but one layer of polygonal shaped cells containing chloroplasts.

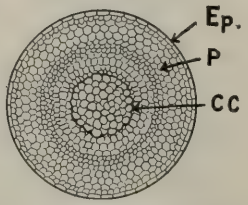

FIG. 40.—CROSS-SECTION OF STEM OF POLYTRICHUM.

Ep., Epidermis; *P.*, Parenchyma; *C. C.*, Central cylinder of conducting cells.

This simple plant consisting of rhizoids, stem and leaves, is a gametophyte. Sexually it is *dioecious*, i.e., any plant is either male or female. The sex organs are antheridia and archegonia, which resemble those of Marchantia. The antheridia are free sacs located among the leaves at the upper tip of the gametophyte (Fig. 41*A-an.*). The archegonia (Fig. 41*B-ar.*) are flask-shaped organs also. In wet weather the moss beds are covered with water and the motile sperm can swim from antheridia to archegonia, thus fertilizing the eggs.

After fertilization a sporophyte develops as in Marchantia. This sporophyte forms a long stalk which grows up into the air. (Fig. 39*B-Sp.*) It has a foot (*f.*) as before

which is buried in the upper end of the gametophyte archegonium and in this way the parasitic sporophyte gets its nourishment from the gametophyte. The long stalk is called a *seta*. (Fig. 39*B-s.*) At its upper end is a large capsule or *sporangium* (Fig. 39*B-c.*). Over this is a leafy cap or calyptra (Fig. 39*C-cal.*). The four-sided capsule (Fig. 39*C-cap.*) is provided with a lid called the *operculum* (Fig. 39*C-op.*). Spores are developed in the capsule. When they are mature the calyptra and operculum fall off and the spores are thrown out by a simple discharging apparatus, the peristome, consisting of sixty-four teeth. The capsule is elevated at the top of the seta so that when the spores are discharged the wind will carry some of them beyond the moss bed where they will have room to grow and develop.

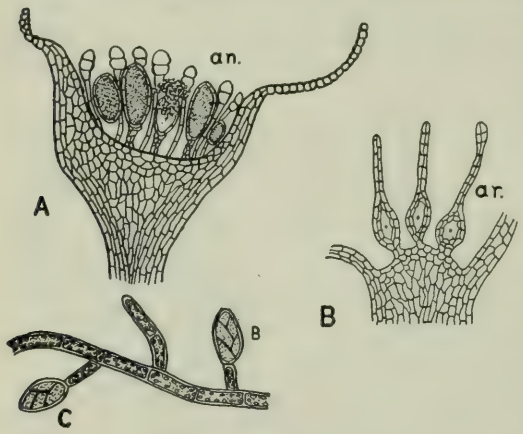

FIG. 41.—POLYTRICHUM.

A, antheridia; *B*, archegonia; *C*, Protonema with buds.

Not all the spores propagate new beds. Those that do, develop into a branching, threadlike or filamentous growth (Fig. 41*C.*) just underneath the surface, but somewhat exposed to the light. This branching filament consists of long cells placed end to end. It is surprisingly like some of the simple Algae and is called a *protonema*. We are tempted to wonder whether this alga-like stage in the life history of a moss plant has any significance. One might conclude that it is an indication of the algal ancestry of mosses. From the filament of the protonema develop buds and these buds (Fig. 41*C-b.*) develop into new upright moss plants with stem and leaves as before. The protonema

does not necessarily die at once, but remains alive and extends further, producing more buds and more moss plants. The protonema is distinctly a part of the gametophyte generation. A gametophyte may develop from any part of a protonema. In Polytrichum we see that there is present a gametophyte and sporophyte generation, which alternate. The sporophyte is much larger than that of the liverwort, but is still parasitic on the gametophyte and does not remain very long; just long enough for the production of spores. The stem of the moss is not very strong and yet further development of it with branches and leaves could hardly have resulted in such large forms as the higher plants. A reason for this is to be found in the fact that it would still be a gametophyte, and as such it would still produce eggs and sperm, and it is highly probable that eggs and sperm, produced at the top of an enormous tree-like moss gametophyte, would all perish because there would be no means of bringing them together and they would dry up. This gives us a possible idea why the higher plants did not evolve by an extension in complexity of the moss plan of structure. The *True Mosses* are the highest representatives of their kind. They stand at the end of a road which, turning off from the liverwort type, ended in the moss and evolved no further. We look upon the liverworts and not the mosses as similar to the ancestors of the higher plants. The *Anthoceros* plant is the most suggestive of all existing liverworts as to how the sporophyte became independent.

Before leaving the mosses, attention is called to a group called the *Sphagnales* represented by *Sphagnum* or Bog Moss. This form is quite well distributed in swampy or wet places in temperate regions. The life history is somewhat similar to that of the Bryales. The gametophyte has a branching stem to which are attached rows of very small leaves. The leaves have some cells which have no protoplasm but which absorb and store water. Between them are chlorophyll containing cells. A mass of dead sphagnum is almost sponge-like in its property of absorbing water. Moreover, it is not rough and coarse like a sponge. If it is cleaned and sterilized, it possesses properties which

make it a very excellent surgical absorbent. In certain localities there are sphagnum beds where sphagnum has been growing for many centuries. New growths form constantly above the old. Season after season this goes on. In this way a thick deposit of old dead plant tissues accumulates. Thus is formed a peat bog. The peat may be cut out in blocks and dried and makes excellent fuel. The plants at the surface are the lineal descendants of ancestors whose dead remains are a number of feet below. Conditions present have prevented the decay of the old growths for this long period of time.

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CHAPTER VII

PHYLUM III. THE PTERIDOPHYTA

General Morphology of the Sporophyte. (*a*) *The Stem.*—Plants which are ordinarily known as ferns are *Sporophytes*. They possess a gametophyte but this is small and so inconspicuous that most people have never seen it. Alternation of generations is present in the plants of this group.

FIG. 42.—PHOTOGRAPH OF FERN. RHIZOME IS SHORT AND HIDDEN AMONG THE ROOTS.

A number of fronds or leaves are shown. The leaf blade is divided into smaller blades called pinnae. Even these are lobed also. (Photo by Author.)

A common form is *Aspidium* (Fig. 42). *Pteris*, another and common form, possesses a woody stem (Fig. 43), which grows a few inches underground and runs parallel with the earth. It is about a centimeter in diameter from side to side. It is brown, or brown-black in appearance and is compressed ver-

tically with two lateral ridges. A study of a cross-section of the stem of Pteris reveals a variety of structures. The outer surface consists of a layer of epidermal cells (Fig. 44-*Ep.*). Beneath this layer are several rows of dark, thick-walled, empty cells. They form a sort of woody sheath under the epidermis and help to give rigidity to the stem. These cells are called *sclerenchyma* (Fig. 44-*O. Sc.*). Inside of these cells is a mass of thin-walled cells which are filled with food. This tissue is known as *parenchyma* (Fig. 44-*P.*).

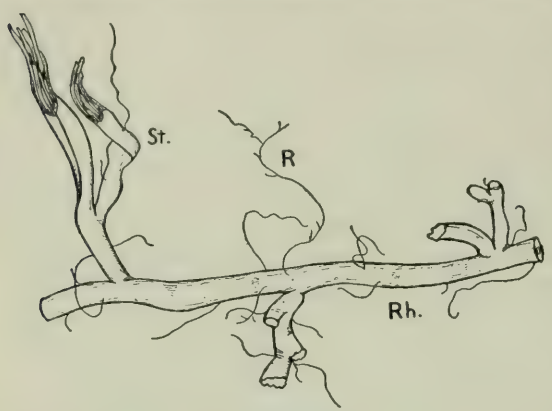

FIG. 43.—RHIZOME OF PTERIS.

Rh., Rhizome; parallel with surface; *R.*, root; *St.*, leaf stalks.

In the center of the stem are found two somewhat rectangular masses of cells like those underneath the epidermis, forming the *inner sclerenchyma* (Fig. 44-*I. Sc.*). They also contribute to the rigidity of the stem. Arranged around these inner masses are shown in this drawing eight oval or circular masses of cells of different appearance. These

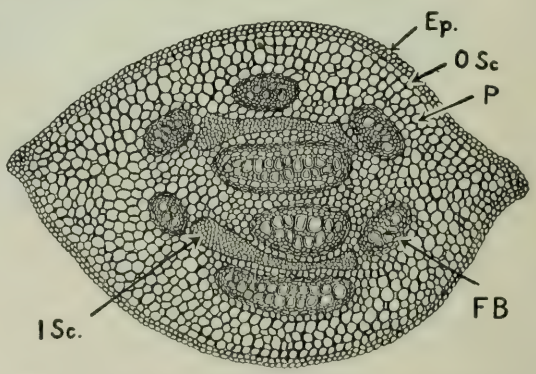

FIG. 44.—CROSS-SECTION OF RHIZOME OF PTERIS.

Note dorso-ventral flattening with lateral ridges. *Ep.*, Epidermis; *O. Sc.*, Outer sclerenchyma; *P.*, Parenchyma; *I. Sc.*, Inner sclerenchyma; *F. B.*, Fibrovascular bundle.

groups of cells are *fibrovascular bundles* (Fig. 44-*F.B.*), and consist of specialized elongated cells fitted end to end which have the special function of transporting fluids in the higher plants. There is great variety in their structure. But the following kinds of cells are found in each of these bundles. First, one type of cell which transports sugar water from the leaves throughout the rest of the plant. These special cells have definite morphological characteristics and constitute what is known as *phloem tissue*. Second, another sort of cells transports soil water, containing dissolved minerals, from the roots to all parts of the plant. Such cells (of which there may be more than one kind) constitute the *xylem tissue*. Other kinds of cells accompany these. In the fibrovascular bundle of Pteris the large xylem cells and accompanying cells occupy the central part of the bundle while the smaller phloem cells and the cells which accompany them are found toward the periphery. Parenchyma cells occur in the bundle, some associated with the special xylem cells and some with the special phloem cells.

It should be remembered that currents are moving slowly in one direction (down) in phloem and in the opposite direction in xylem. The entire bundle is surrounded by a layer of cells called the *endodermis*. It should also be noted that the fibrovascular bundles in Pteris are scattered around the masses of inner sclerenchyma. The supporting tissue and the fibrovascular bundles found in the stem of Pteris constitute a very important advance over the stem structure of mosses. We shall find a great elaboration of xylem and phloem in the stems of the highest group of plants, namely, the *Flowering Plants*. Development of wood or xylem makes for greater rigidity, makes possible greater supporting powers and so a greater extension of the leaf system. Continued extension of the fibrovascular system makes possible the supply of soil water needed by this greater leaf mass.

(*b*) *The Root.*—The stem of Pteris grows in the earth like a root and is for this reason called a *rhizome* (root-like). It extends its growth at one end just as the tip-top of a tree does. But unlike a tree, it dies away at the other end. It branches as a tree forms branches and the branches extend

through the earth, growing at their tip ends just as the branches of trees grow. If the decay at the hinder end of the main rhizome reaches the place where one of these branches originates, then the main rhizome and the branch become separated. The branch may send out other branches and in this way by a process of vegetative reproduction, ferns may extend over a considerable area if they once get started in a locality. If a farmer wishes to clear such an area he must root out every piece of fern rhizome, otherwise any small pieces of rhizome left in the ground may start a new colony. The roots, unlike the roots of a tree, grow out all along the lower surface of the rhizome. As the rhizome grows forward new roots develop. The roots are small and have small branches. Since the stem is underneath the earth large roots are unnecessary, whereas the tree with its great upright stem, is obliged to have large branching roots extending out in all directions from its base.

Fig. 45.—Pinna with sori.

(*c*) *The Leaf.*—At intervals leaf stalks arise from the fern stem. Each leaf blade or lamina is divided into smaller blades like a feather (pinnately). These smaller blades are called *pinnae* (Fig. 45). At the base of the lamina, the pinnae are not only larger, but are also further subdivided. If they are completely divided, the smaller blades are called *pinnules*. In some ferns the laminae are hardly divided at all; in others even the pinnules are subdivided. Subdivision of the blade into pinnae and pinnules makes it possible for the light to filter through and illuminate all the leaves. The leaf stalks have the same general structure as the stem. The leaf also contains a few fibro-vascular bundles in the veins. The structure of the leaf is similar to that of the leaves of higher plants and it is the chief function of the fern leaf to make starch.

(*d*) *Spore Production.*—It was stated above that the large fern plant growing in the woods is a Sporophyte. As

such it produces spores only. On the under side of the pinnules of some ferns are small dot-like bodies called *sori* (Fig. 45). Each sorus is a cluster of sporangia protected below by a scale-like leaf called the *indusium*. The sporangia (Fig. 46) differ in size. The smaller ones are immature. The largest ones are brownish-yellow in color. At the outer end of the sporangial stalk or *pedicel* is a capsule. The capsule is somewhat oval in shape and somewhat compressed from side to side. Along one edge is a row of scalloped-shaped cells forming the ring or *annulus*. It could more properly be termed a spring. The side walls of the capsule are thin flat cells. The annulus originates from the pedicel and extends up around the back edge of the capsule and partly around the other end. In some ferns the sporangia are borne all along the edges of some leaflets on the under side. In other forms some leaves are vegetative, while others are given over entirely to the production of spores (Fig. 47).

FIG. 46. — SPORANGIUM OF FERN. *P.*, Pedicel; *C.*, Capsule; *A.*, Annulus; *Sp.*, Spores.

Inside the capsule spores develop and ripen in the summer. The spore case becomes hard and dry. The annulus, due to this drying, develops considerable tension. Under certain conditions, a rupture occurs in the cells of the capsule. The annulus bends back, widening the rupture. It recoils and the spores are discharged. If the wind is blowing at the time, the spores are carried some little distance from the plant. Thousands of these spores are produced. Each spore is a single cell. It has been produced asexually from the sporangium which is the asexual organ of reproduction of the Sporophyte.

The Prothallus.—Falling upon the earth, the spore absorbs water which softens its hard case. Due to the absorption of water and warmth, the single cell inside is stimulated to divide. Cell division follows cell division. In a short time there is formed a multicellular, small, heart-shaped, flat, leaf-like (*thallus*) structure (Fig. 48) about 3 to 5 mm. in diameter and about 1 mm. thick. It is green

in color. On the under side root-hairs or rhizoids develop and it resembles a liverwort such as Marchantia, though much smaller and simpler in structure. It is called a *Prothallus*, because it precedes the formation of the fern plant. On the under side develop sex organs, *antheridia* and *archegonia*. The archegonia are formed near the notch of the heart-shaped prothallus. The antheridia are formed further back among the rhizoids. Each archegonium resembles the archegonia of the Bryophytes. That is, there is a neck with a neck canal and in the flask-shaped base is a single egg cell. The antheridium is a small case of cells inside which the ciliated male gametes or sperm cells are produced. Both kinds of sex organs are formed on the prothallus of Pteris. It is monoecious. However, the prothalli of some ferns are dioecious. The sperm are motile and require water in which to swim.

FIG. 47.—PHOTOGRAPH OF OSMUNDA SHOWING VEGETATIVE FRONDS AND SPOROPHYLLS.

(Photo by Fread.

When mature the sperm escape from the antheridia and swim about in the water. At the time the sperm are discharged from the antheridia, the archegonia of the same prothallus have not matured, so that these sperm cannot fertilize the eggs from the same prothallus. Therefore, although the prothallus is anatomically hermaphrodite, it is not physiologically so. Despite the anatomical monoecious condition, self fertilization is prevented. One sperm enters the canal, works its way to the egg and fuses with

the egg, completing fertilization. Sometimes the egg is called an ovum. The fertilized egg is called an *oösperm* (ovum-sperm). The union of two gametes is called a *zygote*. The *oösperm* is a zygote.

The fertilized egg cell or oösperm or zygote now begins to divide. It forms two cells, and each of these forms two cells. Each of the four cells continues to divide, forming four groups. Let us call these groups A, B, C, D. The cells in group A, develop into a structure which remains connected with the prothallus in the region of the old archegonium base. This structure is the foot and consists of those tissues which are to act as an intermediary between the green independent prothallus and the new structure about to be described. The cells in group B, develop into the simple stem; the cells of group C develop into a little leaf, the cells of group D into a simple root. In a short time a small plant (Fig. 49) is discovered clinging to the old prothallus. The little leaf grows up through the notch of the prothallus. The little root grows down into the earth among the rhizoids of the prothallus. The small stem is between them. The little *new plant* is still connected to the old prothallus by the foot. Before the new leaf has acquired chlorophyll, this new small plant is dependent upon the prothallus for food for its growth. Just as soon as the new leaf acquires chlorophyll and as soon as the new root can absorb mineral materials from the soil and the stem transport these, then the new plant grows rapidly, extending its leaf, stem and root far beyond the tiny prothallus from which it sprang.

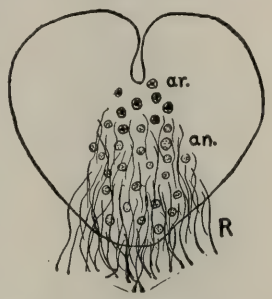

FIG. 48.—PROTHALLUS OF FERN.

R., Rhizoids; *ar.*, Archegonia; *an*,. Antheridia.

Note carefully, however, that it really originated from the fertilized egg. In a sense, the prothallus after fertilization simply mothers it until it can " carry on " by itself. This new structure is a new sporophyte. Eventually it will grow into a large fern plant with its extensive ramifying

underground root-like stem or rhizome from which will spring multitudes of roots and from which will arise at intervals clusters of large leaves.

Alternation of Generations.—Therefore ferns have an alternation of generations. The large fern plant, with which everyone is familiar, is a *sporophyte*. This produces spores asexually. A spore develops into a prothallus which is a gametophyte, bearing sex organs and producing sex cells. The fertilized egg develops into a new sporophyte. However, there is a great contrast to what was found in the Bryophytes. There the *gametophyte* was the conspicuous stage, green and independent. During the greater part of its life cycle, a Bryophyte is a gametophyte. The *sporophyte* is small, inconspicuous, totally parasitic on the gametophyte and lives only long enough to produce spores. In Pteris the gametophyte is small, inconspicuous, short lived, although it is green and independent because it has to nurture the young sporophyte. The gametophyte is simple in structure, much simpler than the gametophyte of the Bryophytes, for example. The sporophyte, on the other hand, is of great size, green, independent, long lived, and has complexity of structure. The tables are turned. The sporophyte has come into ascendancy, and it has come to stay. The gametophyte in the flowering plants is even less conspicuous, but is still retained because it is needed to perform a vitally important function.

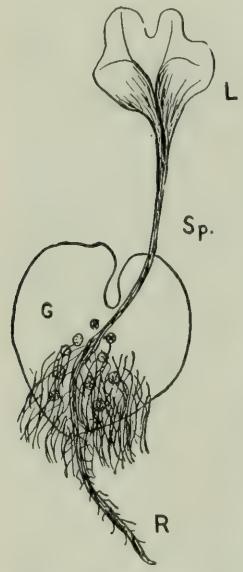

FIG. 49.—YOUNG SPOROPHYTE OF FERN.

Sp., Sporophyte attached to prothallus (gametophyte–*G.*); *L.*, Leaf of sporophyte; *R.*, Root of sporophyte; stem is between these. Sporophyte attached to gametophyte by foot.

There are about 4500 species of Pteridophytes and they are divided into three groups or classes. (*A*) the *Filicineae* or Ferns, (*B*) *Lycopodineae* or Club Mosses, and (*C*) the *Equisetineae* or Horsetails.

(*A*) **Filicineae.**—The greater number of Pteridophytes belong to the Filicineae, or ferns. In general, most of them resemble Pteris. There are three orders of Filicineae but most of them belong to the order Filicales or True Ferns. The stem is not always long and slender, as in Pteris, but may be short and stocky. The leaves may be less or more subdivided. The greatest living Pteridophytes are tropical forms called *Tree Ferns* which may grow to be forty feet in height. They have a rough trunk at the top of which is a crown of large feathery leaves. These tree ferns are the surviving members of the ancient forests of the Coal Age.

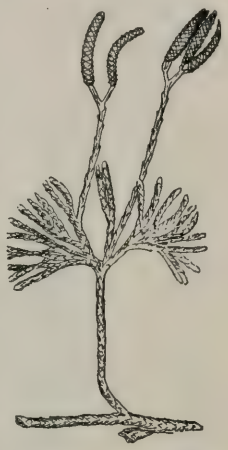

FIG. 50.—LYCOPODIUM —PORTION OF STEM GROWING ON SURFACE AND AN ERECT BRANCH, BOTH COVERED WITH SMALL LEAVES.

The erect branch terminates in five strobili—(cones or clubs) where the spores are produced

(*B*) **Lycopodineae.**—(1) A study of the club moss (Fig. 50), one of the Lycopodineae, shows several points of biological interest. There are about 500 species of the Lycopodiales. The form described here is *Lycopodium*. It is one of the oldest of Pteridophytes, long antedating the seed plants. The slender stem grows on the surface among dead leaves or just beneath the surface. Here and there it sends up many upright branches. The leaves are small and crowded, giving an appearance resembling moss and because of this the plant was called a moss. A study of the stem (Fig. 51) reveals important differences from that of Pteris. It is surrounded by epidermis beneath which is a large cortex with a cylindrical mass of vascular tissue in the center. In the cortex we find schlerenchyma and parenchyma, but it is not broken into separate masses as in Pteris. In this respect Lycopodium shows a more generalized structure than Pteris, which is more specialized. In the central cylinder of vascular tissue we find alternating irregular bands of xylem and phloem tissues not scattered about as in Pteris.

At the ends of some branches are club-shaped structures (Fig. 50). These are compact masses of special leaves called *sporophylls* because they produce *sporangia* from which spores are formed. The " club " composed of sporophylls is called a *strobilus*. In other words, production of spores is limited to certain definite structures at the upper ends of the branches. The rest of the plant is vegetative.

(2) *Selaginella* belongs to another order of the Lycopodineae. It is a delicately branching little plant growing

FIG. 51.—MICROPHOTOGRAPH OF CROSS-SECTION OF LYCOPODIUM.

Under the epidermis is the cortex. In the center is the central cylinder of vascular tissue containing alternate bands of xylem and phloem. (Photo by Bratter.)

prostrate. Two rows of large leaves and two rows of small moss-like leaves grow out flat from each side of the stem. At the tip of the branches are also strobili which are semi-erect. The thing of especial interest is this, namely, that two kinds of spores are produced—small forms which are called *microspores* and the larger called *megaspores*. On germination each microspore produces a single antheridium which produces biciliate sperm only. The megaspore develops into a simple many-celled female gametophyte or

prothallus which produces two or three archegonia with one egg in each. This phenomenon occurs also among a few other Pteridophytes, but it is not the rule. These gametophytes are developed in the microsporangia and megasporangia, as is the case in seed plants.

(*C*) **Equisetineae.**—*Equisetum* is an example. It is very often found on the dry gravel along the road or by the side of railroad tracks and is commonly known as the horsetail or scouring rush. The rootstock or stem lives in the earth from year to year. From it arise vertical stems of two kinds. One is a vegetative or sterile stem (Fig. 52*A*), which is fluted and feels harsh to the touch, due to the silica in it. Nodes appear along its length. At each node is a circle of diminutive colorless leaves. From the axils of these grow green stems, also with nodes with whorls of small leaves.

FIG. 52.—EQUISETUM, THE HORSETAIL.

Left, a sterile or vegetative frond with whorls of branches; Right, a fertile stem ending in a strobilus or cone.

Functions carried on by the leaves of ferns are here carried on by these sterile stems. The cross-section of the stem reveals an interesting structure. The epidermal cells are filled with silica. Air pores occur in this layer. Under this is a zone of chlorophyll cells and next is a zone in which there are large air spaces. Within this zone is another zone in which isolated masses of fibrovascular tissues occur quite regularly arranged. A hollow cylindrical space occurs in the center of the stem. The fibrovascular bundles appear to be arranged radially. That is, the

phloem is always outside the xylem on an imaginary radius in a cross-section. Spores with elaters attached are produced in sporangia which occur in cones at the ends of special fertile stems (Fig. 52*B*). Male and female gametophytes are produced.

Evolution of Vascular System.—A comparative study of the vascular tissues of Pteridophytes shows an interesting series starting with simple conditions and ending in an arrangement very much like that of higher plants, the *Spermatophyta*. For example, in *Gleichenia* (Fig. 53) one of the Filicineae, the xylem vessels occupy the center of the vascular region and are surrounded by the phloem. The vascular region is restricted to the central portion of the stem and is called the *stele*. In *Lycopodium* (Lycopodineae) we found that the stele was composed of irregular alternating bands of xylem and phloem. In *Osmunda* (Fig. 54) (Filicineae) and in *Equisetum* (Equisetineae) we find that the vascular tissue is in the form of a ring (in cross-section) with definite fibrovascular groups arranged radially, having the phloem outside and the xylem always toward the center of each mass. And this is the arrangement found in the seed plants.

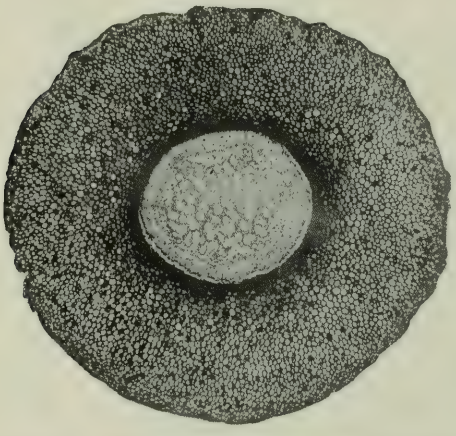

FIG. 53.—MICROPHOTOGRAPH OF SECTION OF GLEICHENIA.

Inside the cortex is the central cylinder of vascular tissue. The center of this cylinder is xylem surrounded by a thin ring of phloem. (Photo by Martin.)

Summary of Pteridophytes.—Pteridophytes are very ancient plants and in bygone ages formed great forests. The carpet-like moss plants with shallow growing rhizoids and simple stem and leaves could not possibly have com-

peted successfully with ferns which could explore deeper into the earth with their roots and could bear an enormous increase of leaf areas because of their *woody stems*. These great leaf expanses drew from the air great volumes of carbon dioxide which, with water, made greater supplies of starch and with nitrates built up more protoplasm, more cells, larger plants, etc. The geologists speak of the Coal

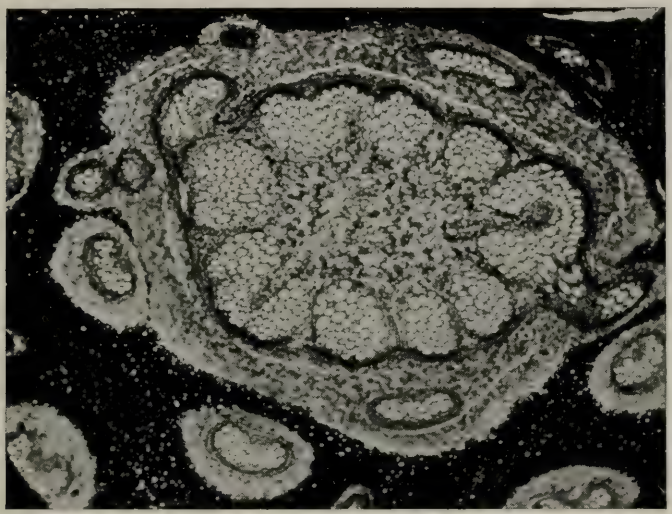

FIG. 54.—MICROPHOTOGRAPH OF CROSS-SECTION OF STEM OF OSMUNDA.

Here the central pith is surrounded by radially located masses of xylem separated from one another by medullary rays. Outside the xylem masses is phloem. Sections of leaf stalks are shown outside the central stem. This type of fern stem approaches most closely that of seed plants. (Photo by Martin.)

Age, the age of Carbon. It could also be called the Fern Age for then the dominant vegetation was forests of great tree-like Pteridophytes, club mosses, horsetails. The vegetation was probably more profuse and extensive than anything on earth to-day. Experiments have shown that greater growth occurs when the percentage of carbon dioxide in the air is increased above the normal amount.

It is claimed that the atmosphere at the beginning of the coal period contained much more carbon dioxide than at present. The Pteridophytes may have reduced this percentage to

what it is now, and final equilibrium which does not vary from year to year. The ancient Pteridophytes converted all that excess, locked it up, as it were, into carbohydrates which did not decay but turned into coal and in this form became the source of heat or energy which is so vitally important to all civilization.

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CHAPTER VIII

PHYLUM IV. SPERMATOPHYTA

General Definition.—The *Spermatophytes* are Seed Plants. (Fig. 55.) These plants constitute the most conspicuous vegetation of our time. Some seed plants, as the giant redwood trees, are the largest of all living things. Seed plants furnish man with a large part of his food supply and other products essential to the existence of civilized peoples. Spermatophytes possess a *root, stem* and *leaf* system. Reproduction is carried out by means of special structures called *flowers*. Formation of seeds is one of the characteristic features of Spermatophytes. The development of flowers and seeds is of the greatest importance in the evolution of the advanced position occupied by the members of this group.

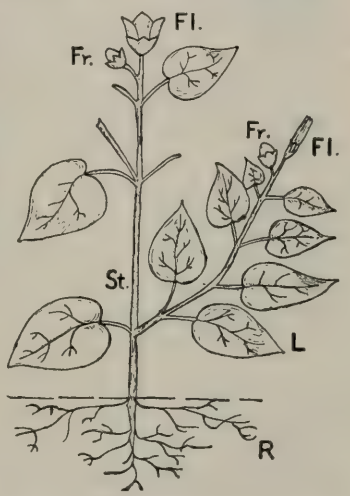

FIG. 55.—DIAGRAM SHOWING PARTS OF A SEED PLANT.

R., Roots; *St.*, Stem; *L.*, Leaf; *Fl.*, Flower; *Fr.*, Fruit (with seeds).

MORPHOLOGY

(*A*) **The Root.**—Roots live in the soil. They anchor the plant, they absorb water, they absorb mineral matter, they absorb oxygen and give out carbon dioxide. Roots may be storehouses of food and of great value to man. In general appearance there is great variety among roots but there are

only two main types. One is illustrated by the root system of grasses. (Fig. 56*A*.) This is called a *fibrous root system.* It consists of a thickly branching mass of small thread-like and string-like roots, which grow out and down from the base of the stem in all directions. Other plants (Fig. 56*B*), like the dandelion, have one main root which grows down into the soil. This is a *tap root* and from it grow smaller and smaller adventitious roots. Carrots, parsnips, beets and turnips are examples of thickened or fleshy tap roots (Fig. 57*A*), in which sugar and starch are stored. When dahlia plants (Fig. 57*B*), are dug up in the autumn, clusters of fleshy roots are found at the base of the stem. These contain a great supply of starch which was formed by the leaves during the summer. Such a cluster of roots is called a *multiple root.* If these clusters of roots are separated into individual roots and planted the next spring, a new dahlia plant will grow from each separate fleshy root.

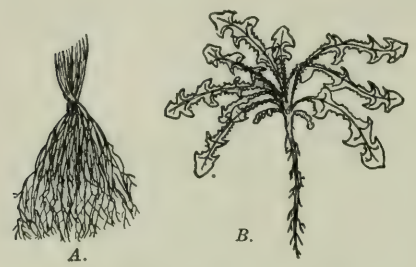

FIG. 56.—TYPES OF ROOTS.

Left, fibrous roots of grass; right, tap root of dandelion.

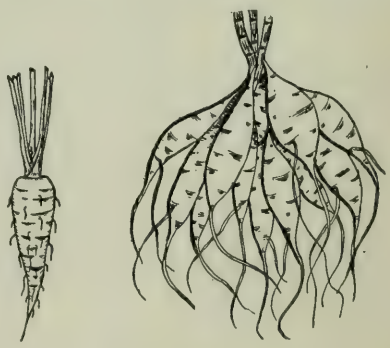

FIG. 57.—TYPES OF ROOTS.

Left, fleshy root of parsnip; right, fleshy multiple root of dahlia.

The older parts of ordinary roots are tough and woody, but the very tip ends of the smallest roots are soft delicate structures and of vital importance to the life of the plant. In the young root of a radish (Fig. 58), we can distinguish the following parts or regions, the *root cap,* the *growing point,* the *growth zone,* and the *zone of root hairs.* A detailed study of the root tip of corn is

shown in Fig. 59. The root cap consists of a covering of cells which protect the tender tissue behind it and especially the growing point. As the root tip grows through the soil, the root cap is pushed in between soil particles and in this process the outer cells of the cap are rubbed off. New cells are constantly formed underneath to take the places of the outer cells when the latter are worn away. Just

FIG. 58.
SPROUTING SEED OF RADISH.

At lower end of root is the zone of root hairs; near the tip is the growing point.

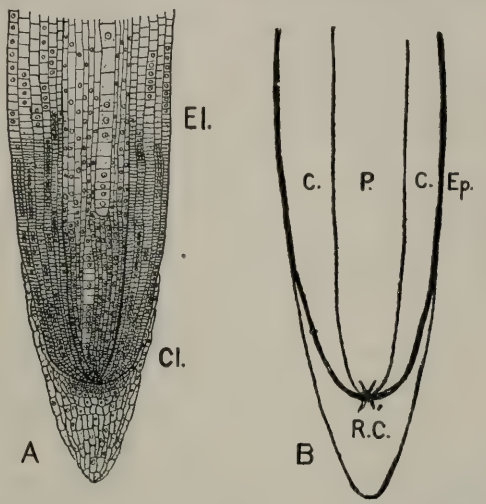

FIG. 59.—DRAWING OF LONGITUDINAL SECTION OF ROOT TIP OF CORN. *B*, SKETCH SHOWING DIFFERENT REGIONS IN THIS.

In *A*, *El.* is region of elongation; *Cl.*, the region where new cells are forming; in *B*, *R. C.* is the root cap; *X.*, the growing point; *Ep.*, Epidermis; *C.*, Cortex; *P.*, Inner region of undifferentiated cells.

back of the root cap is the growing point. This is a center of active cell division. New root cap cells are formed as well as other cells which are permanently incorporated into the root as it grows.

Back of the growing point is the growth zone. This is the place where the permanent cells formed by the root cap mature in which process they increase in length. The region is very short and behind it is the zone of root hairs. For a short distance the epidermal cells of the root tip

develop hair-like processes (Fig. 60), which may be a fraction of a centimeter in length. They are similar to the rhizoids which were found on the under surface of the Marchantia plant and of the prothallus of the fern. The wall is of very soft cellulose and just inside is a thin layer of protoplasm which continues into the main epidermal cell. In the cytoplasm is a nucleus. The cell is not entirely filled with cytoplasm as is the case with animal cells, but has a large sap cavity filled with a watery fluid sap. Sap contains sugar and mineral salts in solution. As the root hair develops from the epidermal cell, it pushes its way out between the minute soil spaces and its walls come into intimate contact with soil water. Root hairs do not live very long. As the root tip grows new root hairs are being constantly formed just behind the newly formed growth zone. Farther back the old root hairs are dying off. Due to the formation of root hairs the surface exposed to soil water is enormously increased. If we compared the total surface area of all the root hairs of a single root tip with the total area of the surface of that same region or root-hair zone, we would find that the first named area is many times that of the second.

FIG. 60.—ROOT HAIR CELL.

The tough bark of old roots is impermeable to the plant fluids within and to the soil water without. But soil fluids must find their way into the plant if life is to go on. Water is needed for the manufacture of more sugar. The sugar supply is constantly used up in the life of the plant. Nitrogen which is derived from the soil must enter if the protoplasm broken down by normal life processes is to be restored or increased. Root hairs are structures which make possible the intake of water from the soil. The wall of the root-hair cell is permeable to water and to the minerals dissolved in the water. It is lined with a thin film of protoplasm, thus forming a sac of living matter inside of which is cell sap and outside of which is soil water. This protoplasmic sac is not freely permeable. It will not permit

the cell sap to escape. In this way the sugar is conserved. It is quite permeable, however, to the substances dissolved in the soil water and to some compounds more than to others. Water can pass through it freely in either direction. Because the concentration of the fluids within is greater than that of the soil water, there will be an osmotic pressure within greater than that without and this sets up a movement of fluid from without the cell, through the living membrane into the sap cavity, a process known as Endosmosis. The concentration of the plant fluids of the inner cells adjacent to the outer root hair cells is greater than in the latter cells, hence there will be a movement of fluids from the root hair cells into the next inner row of cells. For similar reasons there will be a movement of liquids from the second tier of cells to the third and from the third to the fourth and so on. In this way is explained the movement of fluids from without into the various cells of the young root tip. We cannot explain by this process of osmosis alone, how fluids from the soil rise to the top of a large tree.

Everyone is familiar with the fact that on certain very dry days small non-woody plants wilt and that if provided with plenty of water they again stand vigorously erect. Everyone is also familiar with the considerable rigidity developed in an inflated balloon due to the outward pressure of the air imprisoned within. When the balloon is deflated, it becomes flaccid or wilts. The sap cavities of plant cells are well filled with water which has been absorbed by osmosis and the cells are rigid, due to the outward pressure of the contained fluids on all parts of the cytoplasmic and cellulose membrane. The rigidity of each cell may not be very great but there are millions of cells and the sum total of all their rigidities is sufficient to maintain erectness. This outward bearing pressure of contained liquids of a plant cell, due to osmotic pressure, is known as *turgor*. If the cell fluids become depleted due to conditions of drought, then turgor is absent and the plants droop or wilt. The cells of the young root possess turgor.

An examination of a cross-section of a young root of the

buttercup somewhat back of the tip reveals the fact that it is surrounded by an external single layer of epidermal cells (Fig. 61). This is a protective layer. Just inside the epidermis is the *cortex*, or parenchyma. The cells are polygonal in shape, of soft-walled cellulose and starch is stored in them. (See Pteris.) The cortex of a fleshy root, like the parsnip, is very large. Inside the cortex is the central cylinder. The tissues inside it are separated from the cortex by a single layer of cells which resembles the epidermis and is called the *endodermis*. In the central cylinder or *stele* is found the fibrovascular tissue. Here we find alternating masses of xylem and phloem. In a young root there would be at least four masses of each.

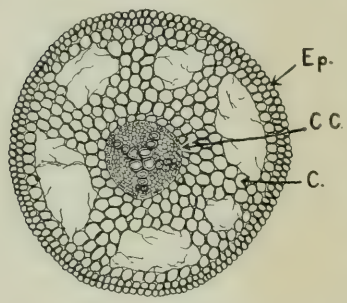

FIG. 61.—CROSS-SECTION, YOUNG ROOT OF BUTTERCUP.

C., Cortex with air spaces; *C. C.*, Central cylinder of vascular tissue. Four masses of large cells or xylem with phloem in between them. The central cylinder separated from cortex by a single layer of endodermis.

The xylem consists of groups of large, thick-walled woody cells, giving rigidity to the root. It is in these highly differentiated elongated cells that soil solutions are carried up from the soil. Alternating with the xylem cells are groups of phloem cells. These are thinner walled and of special form. It is in these that sugar solutions are carried down to the cells below. In the center of the cylinder and between the groups of xylem and phloem cells are cells resembling the parenchyma tissue of the cortex. The innermost cells were the first cells formed when this part of the root was root tip. The plan of arrangement is shown also in a diagram (Fig. 62) of the cross-section of a young root in this region. A branch rootlet may grow out from such a young root. It arises from the embryonic tissue in the central cylinder and grows out through the cortex. In structure it is similar to that of a root tip.

The structure of a still older root, one which is two or three years old, differs from the young root previously

described where the only cell-forming tissue is confined to cells between the xylem and phloem tissues. This becomes continuous until it forms a thin cylinder in the entire root. This embryonic layer of cells which retains the power of forming new cells is called the *cambium*. In the very center of the root are found the original xylem masses surrounded by wood. Outside of this is more wood that has been formed during the second season. Radiating lines of cells can be seen extending part way through the wood. There are more of these streaks toward the periphery. These lines are sectional end views of flat plates of cells which extend a short distance up and down the root and are called *medullary rays*. They contain cells which provide for the transfer of fluids across the root. Outside the woody region is the circular line of cells, the cambium.

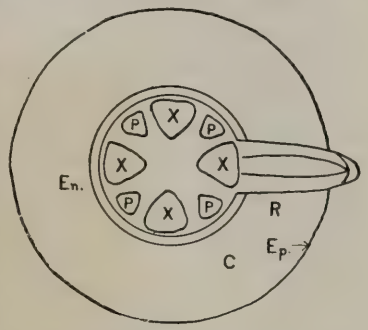

FIG. 62.—DIAGRAM SHOWING ARRANGEMENT OF TISSUE IN A YOUNG ROOT.

Ep., Epidermis; *C.*, Cortex; *X.*, Xylem masses; *P.*, Phloem; cambium is between xylem and phloem; *En.*, Endodermis surrounding vascular cylinder; *R.*, Young root branch growing out from central cylinder.

Cambium cells are roughly rectangular in shape. Figure 63 shows how the cambium forms xylem and phloem. The cambium cell *C* divides, as shown, into two small cells *c* and *x*. After formation *c* grows again into another cambium cell *C* which can later divide again. But *x* develops into a xylem cell *X* which is outside of other xylem cells previously formed. Another cambium cell *C'* divides into two cells *c'* and *p*. *c'* grows into another typical cambium cell, while *p* develops into a phloem

FIG. 63.—DIAGRAM SHOWING FORMATION OF XYLEM AND PHLOEM FROM CAMBIUM.

cell *P* which is just inside other phloem cells previously formed. The constant growth of the young cambium, young xylem and young phloem cells has the effect of constantly pushing the phloem out and out. Every now and then a cambium cell divides at right angles to its length. This makes a larger number of cells around the circle, hence the cambium is constantly increasing in circumference. In the phloem outside the cambium are found the remnants of the first-formed phloem masses, which in the young root previously described were in the center and alternated with the xylem. Surrounding the phloem ring is found a region of cork-like protective tissue called the *periderm.*

The wood increases in thickness year by year and accounts for the increase in thickness of the root. Its increase in length takes place at the growing zone of the terminal root tips.

(*B*) **The Stem.**—Materials are conducted from the roots to the leaves through the stem and substances pass from the leaves through the stem to all parts of the plant. The number of leaves is potentially increased to a great extent by the branching habit of the stem. There is an almost endless variety in the form and structure of stems.

Herbs have relatively soft and tender stems. These stems die down to the ground during the winter or other unfavorable conditions. New stems grow up when the proper conditions again prevail. A rose bush is an example of a shrub. A shrub is a comparatively low growing bushy mass of woody stems which do not die down in the winter. Such plants usually do not attain any great size. A lilac is another example of a shrub. A tree possesses one main stem or trunk which in some species attains great height and diameter. Its woody structure enables it to support a great mass of leaves and branches. The branching habit of trees is quite characteristic of each species, so much so that in many cases the tree may be identified by its form. The branches help the leaves to reach the sunlight and the air.

An *annual plant* is one which develops from the seed,

produces root, stem and leaves, flowers and seeds all in one season. Examples are peas, beans and many common flowering plants. A *biennial plant* develops only roots, stem and leaves from the seed during the first season. It, however, forms a fleshy root in which a surplus of starch, made by the leaves, is stored. In the spring of the second season leaves develop from this, flowers and seeds are also produced. Two growing seasons are required to complete the cycle. We purchase seeds of beets, carrots and turnips, from the seedsman. We harvest the fleshy roots at the end of the summer, but do not attempt to raise our seed supply. The seedsman plants the fleshy roots and from the plants which develop he gathers a harvest of seeds at the end of the season.

Perennial plants, such as shrubs and trees, live year after year. Some produce seed in one year and some of them, such as the pine tree, take two years to develop seed.

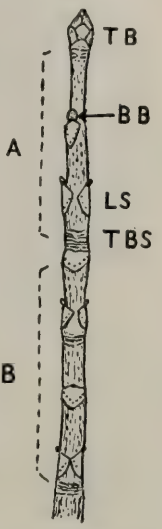

FIG. 64.—END OF YOUNG BRANCH OF THE HORSE-CHESTNUT.

A, Portion formed during current year; *B*, Portion formed during previous year. *T.B.*, Terminal bud; *B.B.*, Branch bud; *L.S.*, Leaf scar; *T. B.S.*, Scars of former terminal bud leaves.

Figure 64 is a diagram of the end-portion of a branch of a horse-chestnut tree taken in the autumn, after the leaves have fallen. The space *A* is that portion of the branch formed during the preceding summer. Part *B* was first formed during the summer before and is thus two years old. The remaining part was first formed the summer before that and is therefore three years old. Scars of leaf stalks which later fell off are indicated (*L.S.*). Buds are found along the stem. *B.B.* is an older lateral bud and *T.B.* is the terminal bud. Lateral buds may develop into branches. *T.B.S.* shows scars due to falling off of bud scales of a former terminal bud. The structure of a bud shows many points of similarity to that of a root tip (Fig. 65). It has a growing point. When the bud-leaves unfold the

growing point of the tip of the stem is exposed to the air. Adjacent to the terminal bud are very small lateral growing points which are the places of origin of new branches. If this terminal bud is broken off it will mean the loss of several potential branches and moreover prevent the loss of fluids from the delicate cells inside the bud tissues. The tissue just behind the growing point resembles that of the corresponding region in a young root, namely, an external epidermis. Under this epidermis is the cortex with parenchyma cells. In the center is a similar tissue, the pith, and between the pith and cortex are strands of cambium or *meristematic tissue*. Meristematic tissue is composed of cells which possess the power of cell division, that is, new cells can be formed from this tissue.

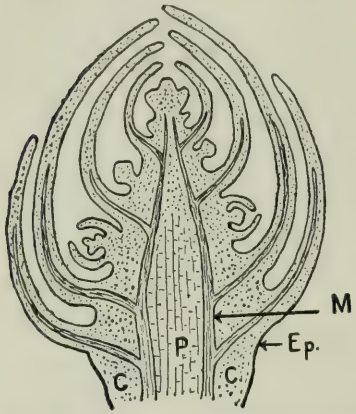

FIG. 65.—DIAGRAM OF SECTION OF TERMINAL BUD. EMBRYONIC BRANCHES AND LEAVES PROTECTED BY BUD LEAVES.

Ep., Epidermis; *C.*, Cortex; *P.*, Pith; *M.*, Cambium or meristematic tissue.

Figure 66 is a diagram of a cross-section just back of the growing point. Here again is seen the epidermis. Under this is the cortex. The superficial cells of the cortex may contain chlorophyll. Air pores, which will be described in more detail in the study of the leaf, occur in the epidermis. Inside the cortex and outside the pith are seen four fibro-vascular bundles. Each is somewhat triangular in shape, and consists of three kinds of tissue. First, a group of phloem cells toward the periphery of the stem; second, a group of xylem cells toward the center of the stem and between these two a thin line of

FIG. 66.—DIAGRAM OF YOUNG STEM.

Cambium is restricted to each fibrovascular bundle. Four of these indicated. Xylem inside and phloem outside cambium in each.

cambium. A radius passing from the center of the stem to the periphery and bisecting one of these fibrovascular bundles would begin in the pith and then pass through xylem, cambium, phloem, cortex and epidermis. Radiating from the center of the stem and located between the fibrovascular bundles are masses of cells forming the medullary rays. All of these tissues have the same functions as those described in the study of the root.

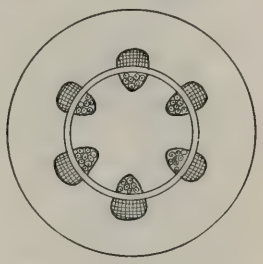

FIG. 67.—DIAGRAM OF OLDER STEM.

Cambium ring is completed and more bundles formed.

Figure 67 is a diagram of the structures further back from the tip, i.e., somewhat older than that of Fig. 66. Here are shown six fibrovascular bundles. Cambium has now formed between the bundles (interfascicular cambium) forming a complete ring in cross-section. Figure 68 is a plan of the stem structure still further back (i.e. older), where new fibrovascular bundles have made their appearance in between the earlier ones. Figure 69 is a diagram of the structure of the stem after one complete season's growth. In the center is the undifferentiated pith structure. Outside of this is a complete ring of xylem. The earlier xylem cells (spring wood) are larger; the later xylem cells (summer wood) are smaller. Outside the last xylem cells is the cambium ring. Outside this is the phloem (bast). Outside the phloem is the cortex and outside the latter is the epidermis.

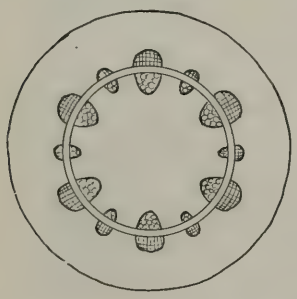

FIG. 68.—DIAGRAM OF STILL OLDER STEM.

New fibrovascular bundles forming in between older ones.

Figure 70 is a diagram of a section of part of a stem two years old. Two so-called rings of wood (xylem) are indicated. These are marked off from one another by the smaller xylem cells of the preceding autumn occurring next

to very large spring wood cells (xylem) of the second season. New medullary rays have appeared in between those begun during the first year. Thus rings of wood succeed each other year after year. In animals worn-out cells disappear, but in plants old xylem cells are retained and make up the great mass of the trunk of the tree.

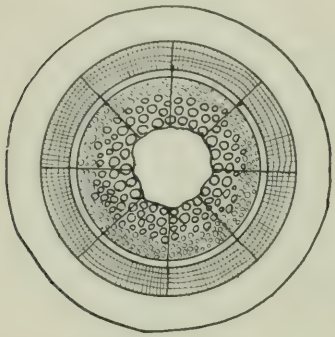

FIG. 69.—DIAGRAM OF STEM AT END OF FIRST YEAR.

The xylem and phloem now form complete rings.

Wood is a carbohydrate compound. In a sense it is stored-up carbon dioxide and water. It contains a good deal of potential energy which came from the sun. When wood decays or is burned up, this carbon dioxide is returned to the soil and may in time be built up into wood again. Old phloem becomes bark. Not all the bark formed during all the years of a tree's life is retained. In contrast to the wood, the outer layers of bark are continuously being shed. The shag-bark hickory illustrates this. The oldest bark hangs in strips or shreds ready to be dropped as the newly formed phloem pushes it out from within. Fluids are usually transported only in the phloem and xylem regions *adjacent* to the cambium although stems differ in this regard. In some stems the sap wood is a very thin layer. In the beech, for example, sap is conducted by a few layers of cells of the last year's growth.

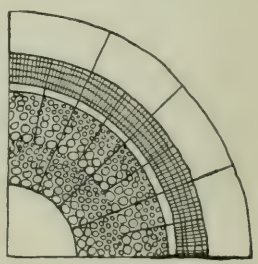

FIG. 70. — DIAGRAM OF STEM TWO YEARS OLD.

Two rings of wood (xylem) shown inside cambium. Spring wood cells larger in each case.

Figure 71 is a drawing of the cross-section of the one-year old stem of *Aristolochia*, Dutchman's Pipe. The fibro-vascular bundles are shown. This should be compared with Fig. 67. Figures 72, 73 and 74 are microphotographs of

respectively one-year, two-year and three-year old stems of *Tilia*, the basswood. These should be compared with Figs. 69 and 70.

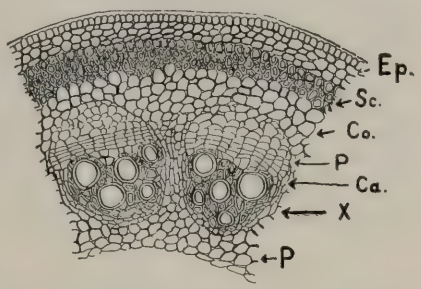

FIG. 71.—DRAWING OF PART OF STEM OF ONE-YEAR OLD ARISTOLOCHIA.

Ep., Epidermis; *Sc.*, Sclerenchyma; *Co.*, Cortex; *P.*, Phloem; *Ca.*, Cambium; *X.*, Xylem; *P.*, Parenchyma. Two fibrovascular bundles are shown.

Xylem (Fig. 75) consists of various types of cells which lack protoplasm and so are dead. They are merely the cellulose walls of cells that lived long enough after they were formed from cambium to assume the size and form of mature xylem cells. They are of different diameters, but are elongated and fit end to end to form conduits for soil fluids. Secondary xylem cells have pits in their side walls, and are called *ducts* or vessels. They are accompanied by long thick-walled cells called *fibers*. Medullary rays are composed of flat cells as shown in Fig. 75. Fluids can pass from vessel to vessel. The phloem (Fig. 76) has a characteristic cell called the *sieve tube*. The ends of these cells are perforated like a sieve. Amino-acids and carbohydrates are conducted down from the leaves through these. By the side

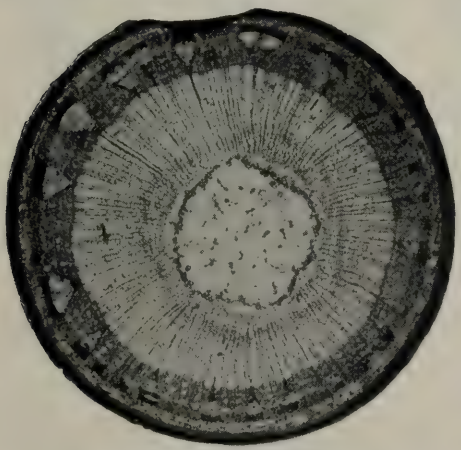

FIG. 72.—MICROPHOTOGRAPH OF CROSS-SECTION OF STEM OF ONE-YEAR OLD TILIA.

In center is pith; outside this is one ring of wood. Radiating lines are medullary rays. Outside wood ring (xylem) is phloem. Medullary rays in phloem have triangular expansions. (Photo by Bratter.)

of many of the sieve tubes are small *companion cells.* These have some unknown function in connection with the *sieve tubes.*

Seed plants, whose stems have the structure described above, belong to a group known as the *Dicotyledons.* (Fig. 77 and 77*A*.) Elm, oak and apple trees are examples. Grasses, palms, bamboo and corn are examples of another group called *Monocotyledons* (Fig. 77*B*). The stems of monocotyledons differ markedly from that of the dicotyledons. The mono-

FIG. 73.—MICROPHOTOGRAPH OF CROSS-SECTION OF STEM OF TWO-YEAR-OLD TILIA.

Compare with Fig. 72. (Photo by Ruckes.)

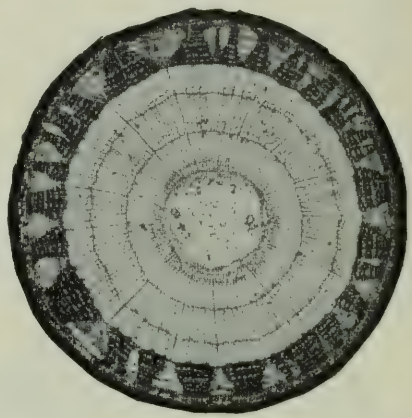

FIG. 74.—MICROPHOTOGRAPH OF CROSS-SECTION OF STEM OF THREE-YEAR-OLD TILIA.

Compare with Figs. 73 and 72. (Photo by Ruckes.)

cotyledons were formerly thought to be older forms than the dicotyledons, but it is now thought that they have been derived from the dicotyledons. Figure 78 is a diagram of a portion of a cross-section of the stem of the corn plant. There is epidermis on the outside and parenchyma is the ground tissue in which are found scattered fibrovascular bundles. Near the periphery will be seen many small fibrovascular bundles. Toward the center of the stem we find larger and fewer bundles. These are older and fully mature. When examined, the structure of a mature bundle (Fig. 79) shows an irregular ring of bundle-sheath cells which separates

the bundle from the parenchyma ground-work. The xylem consists of three large cells, at one end of the bundle and adjacent to one of these xylem cells is a large air space. Opposite to the xylem cells is a mass of phloem cells composed of sieve tubes and companion cells. Monocotyledon stems have no mechanism for yearly increase in thickness as is the case with dicotyledon stems.

In discussing the annual growth in thickness of dicotyledon stems we noted the formation of spring wood in which

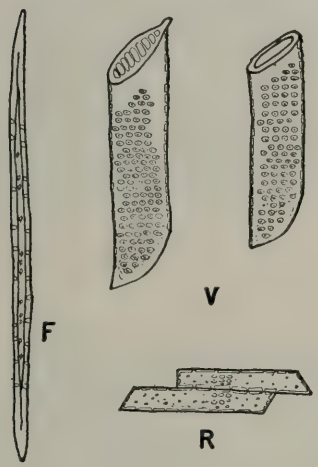

FIG. 75.

F., Fiber cells; *V.*, Vessels (xylem); *R.*, Medullary ray cells. (From Sinnott's Botany.)

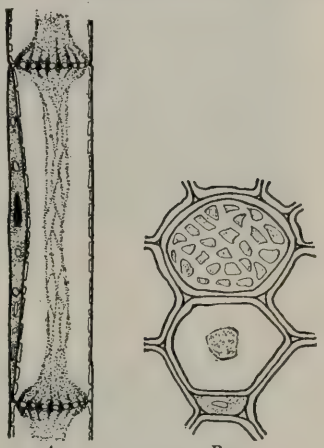

FIG. 76.

A, Diagram of sieve tube with long slender companion cell; *B*, Sectional view of sieve tube (above). Below is a companion cell with its sieve tube. (From Sinnott's Botany.)

the xylem cells were large and that later in the season the summer wood consisted of smaller cells. Conduction takes place chiefly in the spring wood, while the summer wood contributes to the strength of the stem and so provides for its supporting function. To get the most boards out of a woody trunk the saw cuts tangential layers beginning on one side of the log. In some woods, boards are cut so as to show the medullary ray plates. Radial sections of the log are cut to show these in surface view. Such boards, when polished, give a very beautiful effect. Oak lumber

FIG. 77.—PHOTOGRAPH OF ELM—A DICOTYLEDON.

(Fread.)

FIG. 77A.—PHOTOGRAPH OF SYCAMORE—A DICOTYLEDON.

(Fread.)

FIG. 77B.—PHOTOGRAPH OF PALM—A MONOCOTYLEDON.

(Fread.)

is very effective for this purpose and cut in this way is called quartered oak. It can be seen that there is considerable waste which adds to the price.

(*C*) **The Leaf.**—A biological explanation for the evolution of woody trunks with their extensive branching habits is, that such formation exposes a great mass of leaves to the sunlight. A typical leaf has a flat, thin blade where the work of vital importance to the plant is carried on. This is supported by a small stem-like structure called the *petiole*. There is great variation in the size, shape and many other characteristics of leaves. For example, there may be one single blade in *simple* leaves, or the blade may be divided into a number of small leaflets. Such leaves are called *compound*. The leaves of monocotyledon plants (corn) have large veins running parallel. The leaves of dicotyledon plants, on the other hand, show a network of veins. The petiole is a small stem and possesses the structure of a stem with fibrovascular bundles. The veins of the leaf are also miniature continuations of stem structure ramifying throughout the leaf carrying fibrovascular or circulating tissue out to the leaf cells.

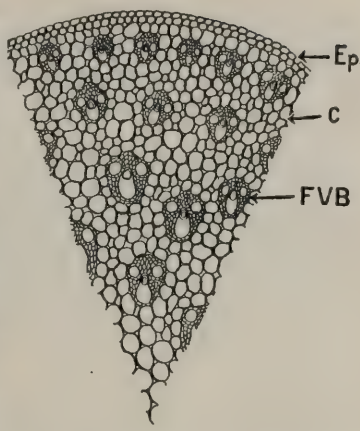

FIG. 78.—DIAGRAM OF A PORTION OF CROSS-SECTION OF CORN STEM.

Note outer epidermis; cortex of parenchyma tissue and scattered fibrovascular bundles. Those near periphery are smaller and more numerous

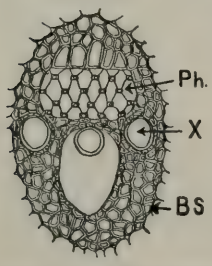

FIG. 79.—CROSS-SECTION OF A SINGLE FIBROVASCULAR BUNDLE OF CORN STEM.

It is separated from parenchyma by a layer of bundle sheath cells. Three large xylem cells are shown. The middle one is inside a large air space. Above these are shown the ends of the sieve tubes. Note small cells adjacent to sieve tubes. These are companion cells.

Figure 80 shows the structure of the leaf. On the upper surface is a row of protective epidermal cells. There is no

chlorophyll in the cells of the upper epidermis. The lower surface of the leaf is also protected by another layer of similar epidermis. Between the two epidermal layers is the *mesophyll.* The cells here are divided into two regions. In the first place, there is a layer of long cells at right angles to the upper surface, the palisade parenchyma. Beneath these cells is the spongy parenchyma where the cells are arranged irregularly with air spaces here and there. The cells of the palisade and spongy parenchyma contain chlorophyll bodies. Palisade and spongy parenchyma is called mesophyll. It is in the mesophyll that starch is made. In the lower epidermis are air pores. These are called *stomata,* through which gases can pass in and out of the leaf (Fig. 81).

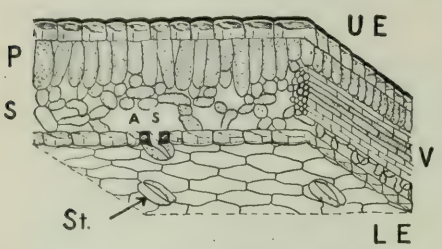

FIG. 80.—DIAGRAM OF STRUCTURE OF A LEAF.

U. E., Upper epidermis; *L. E.*, Lower epidermis; *P.*, Palisade parenchyma; *S.*, Spongy parenchyma; *A. S.*, Air space; *V.*, Vein; *St.*, Stoma. (From Sinnott's Botany.)

Each stoma is a slit between two special, somewhat crescent-shaped epidermal cells called guard cells. Unlike the ordinary epidermal cells, they contain chlorophyll bodies. When these cells contain ample cell sap, i.e., when their turgor is great, they pull apart, thus facilitating the movement of air in and out of the leaf and permitting water vapors within to escape. When the guard cells are flaccid, i.e., when the turgor is lessened, the stomatal opening is closed, thus preventing the entrance or exit of gases. Here, scattered in the mesophyll, are veins, containing the fibrovascular bundles. Each vein is surrounded by a bundle sheath enclosing xylem and phloem cells. The very smallest veins

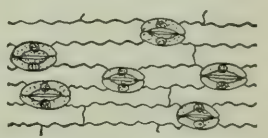

FIG. 81.—DIAGRAM OF A FEW EPIDERMAL CELLS OF A LEAF SHOWING FIVE STOMATA.

Each opening is between two guard cells. These guard cells contain chloroplasts.

possess but one or two of these cells. The epidermis is coated with a non-cellular waterproof layer called *cuticle*. This is thicker in some leaves than in others. It has been claimed that the difference in thickness is due chiefly to the variations in thickness of the epidermis and not of the mesophyll, which in all leaves is more constant.

(*D*) **The General Biology of the Plant.** (*a*) *Roots.*—The principal functions of roots are to anchor the plant firmly to the ground; to absorb water and mineral matter from the soil; to absorb oxygen, and to exhale carbon dioxide; to store water and food, and to support plants which do not possess rigid stems, but which clamber over other plants. If most of the roots are removed the plant dies. We can cut off a stem near the ground and new stems grow up again, but serious injury to the root system will kill the plant. Corn plants develop bracing or prop roots near the base of the stem (Fig. 82). Roots grow out into the soil seeking the optimum water and food supply. Liebig once said that they apparently had eyes for this purpose. This is not literally true, of course. It can be explained as a growth response to the stimulus of water. If necessary, roots will grow deep into the soil after water. Wheat plants have been known to send roots fifteen feet deep into the soil. The *mesquite* shrub may send roots over fifty feet down into the soil. Roots hold or bind the top soil together and prevent it from being washed away by the rain. Complete destruction of forests oftentimes has been followed by the

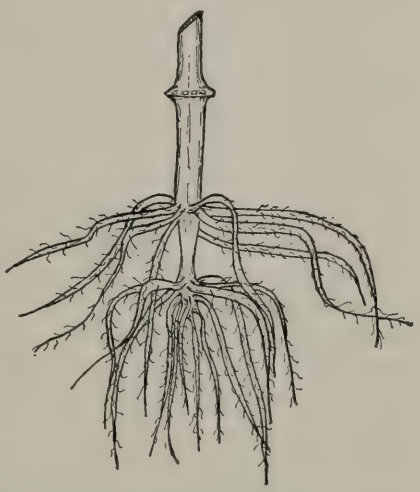

Fig. 82.—Lower end of stem of corn showing upper tier of prop roots formed after the earth was "hilled up."

loss of the top soil which is rich in plant food. This top soil is essential to plant growth. The destruction of forests also decreases the rainfall. It is claimed that on this account areas of the earth's surface, once fertile, are now arid and infertile. The fertility of a region depends partly upon the mineral content of the top soil, and on the amount of nitrates and phosphates and humus present. In France, where intensive gardening is carried on, it is said that when a gardener moves from one place to another he carries with him the top soil of his old garden. Great quantities of this top soil are washed annually by the rain into rivers and so into the sea.

Although most roots cannot breathe if immersed in water, yet some plants are so constituted as to permit this. Roots of willow trees growing alongside a stream are often submerged in the water and the trees seem to thrive. On the other hand, some plants grow in the air and their roots can take in moisture from the air. Some plants can be propagated from roots. For example, the dahlia possesses a multiple fleshy root. When one of these is placed in the ground in the spring new dahlia plants develop. Pieces of the root of rose bushes, when carefully handled, will produce a new rose plant. Poplar trees grow very rapidly. In the landscape development around new homes it is often customary to plant poplar trees for this reason. However, when once started, and if the conditions are favorable, these trees form long roots running out into the lawn and from these roots many new young poplar trees spring up. Some seed plants live on other seed plants. The first type may be partially or wholly parasitic on the second—the host. In such cases the parasite sends a special root-like structure into the tissue of the stem of the host and thus derives its food supply from the host. In this way it may obtain sugar and mineral salts, as in the dodder, or as in the case of the mistletoe, chiefly the mineral salts and water.

Some bacteria live in beneficial relationship with the roots of some plants, as is the case of nitrogen-fixing bacteria and the root of leguminous plants, like the bean, pea, clover and

alfalfa. In addition to bacteria, it has been found that certain molds grow on the tips of the roots of certain trees, such as pines, oaks and beeches. These fungi cover the root tips with a tangled mass of threads and probably take the place of root hairs. Moreover, the trees do not thrive unless these fungi are present.

The soil constitutes one of the two great environments of plants. The greater part of the weight of soil is made up of rock particles. The size of these particles varies and they are of irregular shape with air spaces here and there between them. Well-tilled soil makes for a greater number of air spaces. Plants will not grow well in very compact soil. Rain falling upon soil percolates slowly down through it. If the soil is packed down the rain does not penetrate but runs off. If the soil is composed exclusively of rock particles it penetrates too rapidly and may collect over waterproof layers too far beneath plants to be of any use to them. If the rock particles are mixed with decayed organic matter, or humus, the surface water not only percolates more slowly through the soil, but more is retained. In comparatively dry soils a thin film of water is found adhering to the rock particles. This is of little use to the plant because the rootlets do not possess the power to remove this hygroscopic film. However, if the soil is of the proper constitution a considerable supply of water will be found associated with it in the same way as water associates itself with the cotton fibers of a lamp wick, namely, by capillarity. If the tips of the roots are absorbing this capillary water from one point, the adjacent water of capillarity will move from the points of greater saturation to the region of less saturation in the same manner as fluids are transported from a reservoir up a lamp wick to the tip of the wick where the fluid disappears by evaporation, in the case of water, or oxidation in the case of alcohol or oil used in lamps. Air is vitally necessary for the life of the ordinary root unless there is some special structure present to obviate the immediate absorption of water directly by the root. Well-tilled soil makes for greater water-holding power, for conservation of water and for ample air supply. It also removes accumulations of

carbon dioxide and encourages the destruction of injurious bacteria which may otherwise accumulate.

This soil water dissolves chemical substances necessary for plant growth. Compounds of sulphur, potassium, calcium, magnesium, phosphorus, iron and nitrogen are found in soil. Long-continued growth of crops on a certain area of land diminishes the amount of these compounds. Unless they are restored to the soil the crops grown will be poor or failures. The principle involved in the use of commercial fertilizers is to restore these compounds to the soil.

Organic matter comes from the decay of dead animals and plants. Certain groups of bacteria break down the complex compounds of dead tissue into simpler and simpler compounds. The final results are water, carbon dioxide, ammonia and the most important of all, a final compound of nitrogen, namely, nitrates. These soil nitrates are absorbed with the other mineral compounds and are transformed by the cells of the plant into protoplasm. In this process water and oxygen and sugar in the plant cells are necessary.

Rodents, insects, earthworms, bacteria, roundworms, etc., inhabit the soil. The living animals burrowing through the soil cultivate it to a certain extent. They aerate it. The beneficial effect of earthworms on soil was thoroughly investigated by Charles Darwin. By far the greatest beneficial work on soils is accomplished by bacteria. As stated above, they decompose the dead bodies of plants and animals, and this decomposed organic matter forms humus and when mixed with rock particles makes good soil. Certain bacteria, *Nitrosomonas,* change ammonia into nitrites. *Nitrobacter,* another type of bacteria, change nitrites into nitrates. *Pseudomonas radicicola,* another type of bacteria, lives in little masses (Fig. 83), nodules or tubercles, on the roots of peas, beans, clover, alfalfa. Over four thousand of these have been found on the root system of a single plant. These bacteria have the wonderful power of absorbing nitrogen gas from the air in the soil and making a nitrogen compound which can be absorbed by the roots of the plant. In other words, large and vigorous plants may thus grow in soil comparatively poor in nitrates. These are called *nitrogen-fixing*

bacteria. The soil may be inoculated with nitrogen-fixing bacteria. The farmer may plow under a flourishing crop of alfalfa enriched by the nitrogen of the air furnished by nitrogen-fixing bacteria. This crop will decay in the ground and then the soil will be rich in nitrates. He may then grow better crops of corn and wheat on what was previously poor soil. Certain results are of interest here. A crop of clover or alfalfa, plowed under, supplies the soil with about one hundred pounds of nitrogen to the acre. It is as valuable as many loads of manure. A good crop of corn or wheat will remove from fifty to seventy-five pounds of nitrogen per acre from soil. In every case a larger yield follows the prior treatment of the soil with clovers or alfalfa made more luxuriant by nitrogen-fixing bacteria.

FIG. 83.—DIAGRAM OF A TAP ROOT OF A LEGUME SHOWING SEVERAL "ROOT NODULES" OR TUBERCLES OF NITROGEN-FIXING BACTERIA.

(*b*) *Leaves and Stem.*—Leaves make starch and sugar, and the stem carries this food away from the leaves in the form of sugar to all living cells of the plant. The stem also transports mineral salts and water from the earth to the leaf and to other parts of the plant that need them.

The younger parts of woody stems are green and starch can be made there. The cactus is a green stem whose leaves are reduced to spines. The potato plant has green stems and so has the corn plant. Corn plants may grow ten feet high in one season. Pine trees are only three inches high at the end of the same period. Some species grow fifteen inches a year for the first fifty years; then five inches per year during the next fifty years. They may live two hundred years, but during the second century grow but an inch or so in height each year. Hardwood trees grow but part of an inch in thickness during the first half century and after that but a fraction of an inch per year. Forest fires destroy such growths of wood in a few hours. A pine tree takes fifty or more years to produce wood enough to make a board

twelve inches wide, one inch thick and twelve feet long. In a forest where trees are forced to grow close together the lateral branches are shaded so that they fail to grow, and the trees shoot up toward the light, thus forming long, slender trunks. To change this form, trees must be thinned out so as to permit plenty of room and light for those that are allowed to remain. Heavier timber will result from the latter environment.

Stems vary in size, and in some cases it is difficult to recognize the stem, as in the dandelion plant, where the leaves grow in a rosette almost from one point. Some plants have very slender stems, but they thrive by climbing up over other plants or on the side of buildings, as is the case with the Virginia creeper. Some plants have the power of making quite rapid adjustments to the light. The leaves move so that in the forenoon they receive the full force of the morning light and at noon present the blades edgewise to the noon rays, while in the afternoon they are at right angles to the less brilliant rays. In this way injury from too direct light rays is avoided.

Long before man learned that it was beneficial to growth or fruit production to prune a tree, nature had been performing this function, but less efficiently. There is a tendency to produce a wealth of leaves, and the crown of the tree becomes a thick network of interlocking branches. In the case of fruit trees the greater part of the growth goes into branches, causing the center of the trees to get little light. To make a well-balanced tree this thick network is pruned away, in order to permit light to get at the center of the tree. More fruit is developed to maturity as a result.

Plants in swampy places have comparatively large leaves, while the cactus, which thrives in dry areas, has no leaves. The cactus stem is a great water conserver. Enough water is stored in it from a wet period to last through several dry seasons.

When the ground is frozen the water supply is cut off. If the leaves continued to give water, as they normally do, the tree would soon die. So before the ground freezes,

plants prepare for the winter by shedding their leaves. To facilitate this, a layer of corky tissue develops across the petiole near the branch. When the leaf falls, this forms a waterproof layer and serves to conserve the stem fluids. There is no necessity for this in the tropics where the leaves do not fall all at once. Here some leaves fall off in all seasons and new ones are constantly being formed. There being no spring, summer, or winter in the tropics, it can also be easily understood why there are no annual rings formed in the woody stem.

FIG. 84.—DIAGRAM OF AN IRISH POTATO, AN UNDERGROUND STEM.

The "eyes" are branch buds.

Some stems grow underground and store starch. They even have buds, as in the Irish potato (Fig. 84), where the so-called eyes are branch buds. The potato is used as "seed." It is cut into pieces each containing two or three "eyes" or buds, and these pieces are planted. This is a form of vegetative reproduction. The iris has an *underground stem* called a root stock. Bulbs (Fig. 85) have very small stems surrounded by thick fleshy leaves in which food is stored. As an example of these we have the onion and hyacinth. The water lily has an underground stem which develops an aerial stem. Grasses have underground stems and only the leaves are *aerial*. Although a great amount of the world's supply of starchy foods is stored in underground stems and roots,

FIG. 85.—SECTION THROUGH A NARCISSUS BULB.

Note the short stem enclosed by fleshy leaves.

yet the main supply is formed in seeds. The thin watery syrup of the sugar-cane is the source of commercial cane sugar while the sap of the sugar maple is made into maple sugar. One tree can produce about ten pounds of sugar per season.

Physiology of Flowering Plants.—The physiological processes necessary for life are on the whole the same in plants as in animals. No matter how simple or complex an organism is, it must carry on certain kinds of activities in order to live. There are three classes of these functions. First, *Metabolism*, by which is meant the production of energy from foodstuffs. It involves many processes such as digestion, circulation, respiration and excretion. Second, *Adaptation*, or adjustment to the environment. Third, *Reproduction*, which is not exactly necessary for the life of the individual organism, but is essential to the continuance of the species. Plants differ from animals in that they can manufacture food from inorganic materials, while animals depend on organic materials for food.

Metabolism. 1. *Photosynthesis* is the process by which starch is made in the green leaf from carbon dioxide and water. Carbon dioxide is taken into the leaf through the stomata. It enters the air passages and is taken up by the mesophyll. Water is delivered to these cells by the xylem tissue of the veins. We do not know exactly what happens. If we did we would have factories in which starches would be made from carbon dioxide and water. However, we know a little about the process. To accomplish this manufacture in the leaf, energy is necessary. This is furnished by the sunlight and it is apparently the red and blue rays of sunlight that are used. These are absorbed by the chlorophyll, and this, or something in it is the agent which enables the change to take place. The unabsorbed rays of sunlight passing through chlorophyll give a green sensation to the eye. Chlorophyll is soluble in alcohol, ether and chloroform. However, such solutions of it are ineffective as starch formers. Apparently the carbon dioxide and water are split into their component parts and then recombined. The formation of starch

probably occurs in a series of steps. One suggestion is that carbon dioxide and water unite to form carbonic acid gas—H_2CO_3. An enzyme splits off oxygen from this, making formic acid (HCOOH) and oxygen. Then another enzyme splits off more oxygen, making formaldehyde (HCOH) and oxygen. Later molecules of formaldehyde synthesize to form glucose, a monosaccharid ($C_6H_{12}O_6$). The amount of glucose formed increases in sunlight and decreases in the dark. There is a certain optimum intensity of light at which it takes place most rapidly. This means that too intensive light is not favorable. It is not formed in the dark. There is also an optimum temperature. With the increase in the carbon dioxide up to a certain point, there is also an increased production of sugar. Now as fast as the leaf makes sugar it is converted into starch and this is stored in the cells of the leaf. During the night the excess starch stored in the leaf is reconverted to sugar and passed down the conducting tissues to be reconverted into starch and possibly stored in the underground stem as in the Irish potato. A square meter of leaf surface makes about ten grams of starch per day or three pounds per summer. It takes over a thousand liters of carbon dioxide to do this. Photosynthesis is the most fundamental process in all nature. The very life of the animal world as indeed of plants also, depends upon it. Recent work shows a greater photosynthetic manufacture of carbohydrates when the percentage of CO_2 in the air is increased.

2. *Respiration.*—Oxygen is necessary for animal and plant life. Oxidation is the keystone of all the many processes of metabolism. Carbon dioxide and water are the by-products of oxidation. Plants take in oxygen chiefly through the stomata of the leaf and also through the stem and roots. The waste product of respiration is carbon dioxide, which is eliminated through the stomata. Respiration occurs in all plants and animals. Photosynthesis takes place only where there is chlorophyll, respiration takes place in all living cells of plants and animals. Photosynthesis occurs only in the light; respiration continues through the night and day. Photosynthesis manufactures food; respiration

(oxidation) burns up food. In photosynthesis carbon dioxide is absorbed and oxygen is a by-product; the reverse is true in respiration. Photosynthesis stores energy; respiration releases it. Photosynthesis is the process by which the plant (and all organisms) are enabled to secure a supply of energy-yielding material. Sugar and starch are also necessary to the formation of new protoplasm, new cells and growth.

3. *Transpiration.*—Water, which is a by-product in photosynthesis, collects in the air spaces of the leaf in the form of water vapor. From these spaces it passes out through the stomata into the atmosphere. Light, warmth, dry air and wind increase this movement of water. Some of the water (the greater part of it) has arrived in the leaf via the conducting vessels of the veins and stem. Removal of it by this process of transpiration makes it possible for a further movement of liquids up from the earth. When external conditions are favorable to photosynthesis a brisk movement of water to the leaf is essential. The guard cells of the stomata make sugar also and thus increase the osmotic pressure within, which forces the stomatal opening to enlarge and allow the water vapor to pass out more easily. This means aiding the further movement of water up from the earth. Dark, cold, damp, and non-windy days decrease transpiration.

4. *Transfer of Water and Mineral Salts.*—A great number of long ducts of extremely minute diameter traverse the plant. Through these water and mineral salts dissolved in the water pass from the earth to all parts of the leaf. Just what forces are responsible for this movement of fluids we do not exactly know. The cause is probably the resultant of a number of forces. Osmotic pressure of the sap of cells is greater as you pass from the lower to the more elevated cells, and this would tend to create an upward passage of water from cell to cell. Then again, capillarity would explain a partial rise of liquid in these tubes. Transpiration or removal of water from the upper end of the system of ducts would also encourage its movement upward. The very minute diameter of the ducts, which thus present

a relatively large surface area in proportion to the enclosed fluids, probably is an essential part of the mechanism. Capillary attraction would serve to support the very small weight of water at any one point. Variation in osmotic pressure, transpiration, avoidance of a vacuum and atmospheric pressure from below would make for a movement of fluids. Whatever the causes of the upward flow of sap against the force of gravitation may be, water rises to the tops of the tallest trees.

5. *Protein Making.*—From the sugar made in their cells and from nitrates of potassium and calcium, etc., brought up from the soil, the cells of the leaf can make protoplasm for use in further growth.

6. *Enzymes.*—We have already given a general description of enzymes. Many enzymes are found in plant tissue, and life processes are fundamentally dependent upon the presence of these enzymes. Enzymes are produced by the living cells.

Hydrolyzing enzymes add water and split molecules. Thus cane sugar is made into glucose. Such enzymes are *hydrolases*. *Monosaccharids, disaccharids, polysaccharids* are converted from one to the other by means of enzymes.

Lipases act on fats and oils changing them into fatty acids and glycerine, in which form they may be transported. Other enzymes change carbohydrate into fat and fat into carbohydrate.

Proteases convert complicated proteins into amino-acids. The building up of complex proteins and protoplasm itself involves the presence of special enzymes. Fermenting enzymes change sugar to alcohol. Probably all chemical life processes involve enzymes.

The manufacture of starch by enzymes has also been described as follows: First: An *oxidase* changes water and carbon dioxide to formaldehyde; *aldehydase* changes formaldehyde to glucose; a *maltase* changes glucose to maltose; a *dextrinase* changes maltose to dextrine; an *amylase* changes dextrine to amylum, a soluble starch, and finally *coagulase* changes amylum to insoluble starch.

7. *Other Functions.*—The functions which have to do

with maintenance of life of animals include ingestion of food, secretion, digestion, circulation, respiration, assimilation, oxidation, and excretion. In the plant we have noted that in addition to these processes we have photosynthesis and transpiration. By photosynthesis, carbohydrate in the form of sugar or starch is made. This is plant food. Proteins are foods and also fats. Fats are often stored in seeds. Proteins, carbohydrates and fats are the real food of the plant because the definition of food involves that which is a source of energy to the organism or goes into the upbuilding of protoplasm. Mineral salts from soil water and carbon dioxide are the raw materials out of which the food is made. Animals subsist on ready-made food.

Plants do not take in or ingest food as animals do. Instead they take in the raw materials. Living plant cells are all probably capable of secreting enzymes, and digestion can occur in leaf, stem or root. In growing a new potato plant from pieces of potato, before the food stored in the potato can be used by the new young plant, it is digested to sugar which when dissolved in cell sap, can be easily transported. Plants do not possess a closed system of circulating vessels in which there is a continuous flow, as in animals. Plants take in oxygen and give out carbon dioxide, as do animals, but there is no special respiratory system. As the osmotic pressure falls in one cell, that cell probably absorbs water from a neighboring cell nearer to the source of supply. As the carbon dioxide pressure in one cell rises it probably flows into a neighboring cell nearer the exit for carbon dioxide. Gases probably circulate in the fluids of the phloem and xylem.

The word assimilation refers to the building up or formation of more protoplasm from proteins, carbohydrates and mineral salts. Oxidation occurs wherever assimilation occurs. Wherever there is living activity of cells there is oxidation. The principal product of excretion in plants is carbon dioxide and water and we have seen where these are eliminated. It has been suggested that a small amount of nitrogenous wastes accumulate in the leaves during the

summer and that the plant throws these off when it sheds its leaves in autumn. Plants accumulate waste in the form of wood and bark which is formed season after season. Only a small part of an enormous tree is really alive. This includes the leaves and that part of the trunk and roots in the neighborhood of the cambium and also the growing points of stem and roots. The fires of plant metabolism are low as compared with those of animal metabolism, hence it is not surprising that nitrogenous wastes are somewhat negligible in quantity.

Adaptation.—Animals quickly adjust themselves to the external world. Plants more slowly adjust themselves. Adjustment of organisms is possible because of three properties of protoplasm, namely: irritability, conductivity, and contractility, elaborated into tissues or mechanisms of adjustment. The protoplasm of plant cells is irritable, i.e., it is sensitive to changes in external conditions. This irritability is communicated slowly from cell to cell. No nervous system has as yet been discovered to conduct rapid impulses, and there are no sense organs to pick up external stimuli. The plant cannot change its rooting place, but it *grows* in response to the external stimulating or irritating forces. For example, if a plant is placed in a dimly lighted place and illuminated from one side it will respond by growing toward the source of light. Similarly we note how well the root system grows toward the place of greater water supply. A turning or response to a stimulus is called a *tropism.* If the response is toward the stimulus then the tropism is *positive;* if away from this stimulus then the tropism is *negative.* There are various kinds of tropisms. *Thigmotropism* is response to touch or contact; *phototropism* is response to light; *geotropism* is response to gravity; *chemotropism* is response to a chemical stimulus. The stem of a vine, such as Virginia creeper, naturally grows into contact with a wall or some other support. It exhibits positive thigmotropism. Green leafy plants grow toward the light; they are positively phototropic, while their roots are negatively phototropic. Roots are positively geotropic while stems are negatively geotropic. The responses

of plants as a rule are *slow* as compared with those of animals. An animal would rapidly react to an injurious chemical stimulus, while a plant might die under the same conditions, i.e., it could not react rapidly enough to escape destruction.

Reproduction in Spermatophytes.—1. *Morphology of Flowers.* The flower is an organ devoted to the production of *microspores* and *macrospores* (megaspores). These spores develop into miniature *prothalli* which remain attached to the flower and produce sperm and egg cells after which fertilization occurs. The infant sporophyte still remains for a time connected with the old flower where its early life history takes place. Flowers have developed beautiful colors and attractive fragrance. These play their part in carrying out the function of the flower. Colored flowers are in contrast with their background. Blues and reds are usually raised above the green leaves of the plants; yellow is conspicuous against a green background. Flowers that have attractive odors are not always brilliant in color.

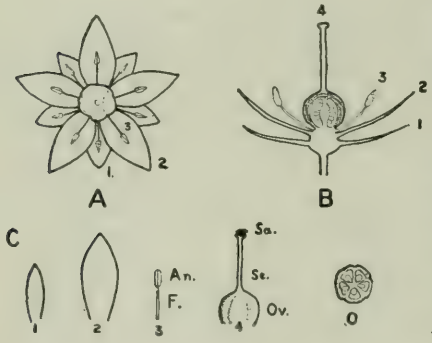

FIG. 86.—DIAGRAMS OF TYPICAL DICOTYLEDON FLOWER.

A., Top view; *B.*, Side view; *C.*, Separated parts. 1, Sepal (calyx); 2, Petal (corolla); 3, Stamen; *F.*, Filament, *An.*, Anther; 4, Pistil; *Sa.*, Stigma; *Se.*, Style; *Ov.*, Ovary; *O.*, Cross-section of ovary with five locules and ovule in each. (From Sinnott's Botany.)

A typical flower possesses four whorls of leaves (Fig. 86). The floral parts often occur in threes or multiples of three in monocotyledons and in fives or multiples of five in dicotyledons. The *calyx* is the outermost series. Each leaf of the calyx is a sepal and sepals are usually green. Inside the calyx is the *corolla.* This has colored leaves called *petals.* Inside the petals (corolla) are the *stamens.* Each stamen possesses a long stalk or filament and at the outer end is a body called the *anther.* In the anther small bodies called

pollen grains are produced. Pollen grains are microspores. Inside the stamens is an organ called the *pistil*, which is a fusion of *carpels*. In some flowers, as the buttercup, the carpels are separate. The pistil (or carpel) has a knob on the top called the *stigma*. It is sticky and sugary. Below the stigma is a connecting neck or *style* and below at the base is an enlarged part called the *ovary*. A cross-section of the ovary (Fig. 87) reveals chambers within. These chambers or *locules* contain *ovules*. Each ovule (Figs. 89, 90) is connected to the wall of the ovary by a tiny stalk called the *funiculus* and has a number (3) of coats inside of which is an oval shaped cell or *megaspore*. At one end of the ovule a passageway occurs in the coats and leads to the *megaspore*. This passageway is called the *micropyle*.

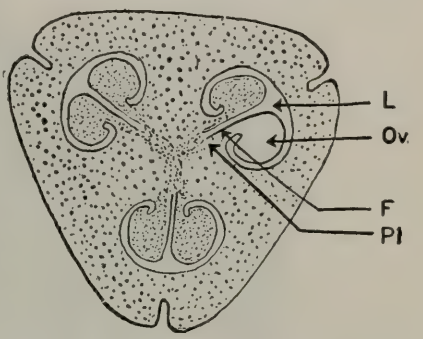

FIG. 87.—DIAGRAM OF CROSS-SECTION OF OVARY OF YOUNG LILY FLOWER.

Note three locules (*L.*); Two ovules (*Ov.*) in each locule; *F.*, Funiculus and *Pl.*, Placenta.

Flowers are necessary for the production of seeds which contain embryo plants. These are the result of fertilization or the union of male and female sex cells. In the lower plants we found that water is necessary for fertilization, and enables the sperm to swim to the egg cells. In the flowering plants it is necessary for pollen to be deposited on the stigma of the flower by other agents. The transfer of pollen from stamens to pistil is called *pollination*.

2. *Pollination.*—Some flowers are so constituted that the stigmas are pollinated from the stamens of the same flower. This is *self* or *close pollination*. The legume plants, peas, beans and peanuts are examples. In the peanut (Fig. 88), development of the seeds occurs in the earth. Self-pollination ensures continuance of the same plant strain or characteristics which at times is very desirable. *Cross pollination* introduces variation. In

most of our trees there are two kinds of flowers: (*a*) *staminate* which produce pollen (microspores), and (*b*) *pistillate* which produce megaspores only. Pollen is produced in great quantities, and the flowers as a rule are formed early in spring before the leaves. Winds carry clouds of pollen, and thus many pistillate flowers become pollinated. In other flowers, insects bring about cross pollination. They may be attracted by the gaily colored petals, or they may be in search of honey (nectar) in the

FIG. 88.—PHOTOGRAPH OF PEANUT PLANT.

The flowers of the peanut are self-fertilized. They are covered with earth and seeds form in the earth. (Photo by Author.)

flower and accidentally carry away a load of pollen whose rough grains stick on the hairy surface of the insect. When the insect visits flowers of the same kind it accidentally rubs off the pollen on the stigma of this flower. Some insects are attracted to flowers by their fragrance. The orchid is so constructed that the insect enters the flower cup by one way and has to leave by another. When entering, it rubs on the stigma the pollen obtained from other flowers, and gets in return a load of pollen from this flower. In some flowers the stamens and pistils do not mature at the same time. In some the pistil is tall, while the stamens are

short and placed lower down. There are others of the same species in which the pistil is short, and the stamens near the upper end of the cup. Pollen from the top stamens will pollinate only the top stigmas, and vice versa.

3. *Fertilization* (Fig. 89 and Fig. 90).—When a pollen grain is deposited on the stigma of a flower of the same species, it develops a *pollen tube.* This is a filamentous structure which grows down the style to the ovary, into the locule, then through the micropyle of an ovule into the megaspore. It has only three cells and is homologous to the gametophyte stage of Marchantia and the prothallus of the fern. One of these cells is the vegetative cell, i.e., it is the miniature plant body. The other two are sex cells, i.e., sperm cells or sperm nuclei. In the meantime, the single-celled megaspore has divided three times, producing an eight-celled structure which is also homologous with the prothallus of the fern, and the gametophyte Marchantia plant. Three of the nuclei of this female embryo sac move to the end opposite the micropyle; two take up a position near the center; and three arrange themselves near the micropyle. One of the latter is an *egg cell.* The three-celled pollen tube is a male gametophyte, and the eight-celled embryo sac is a female gametophyte. They are very short lived. The pollen tube introduces the two sperm nuclei into the embryo sac and the first sperm nucleus moves up toward the endosperm nuclei and fuses with them. The other sperm nucleus fuses with the egg nucleus. The fertilized egg now divides and new small cells form. Division and growth continue until an embryo plant results. In the meantime the cell formed

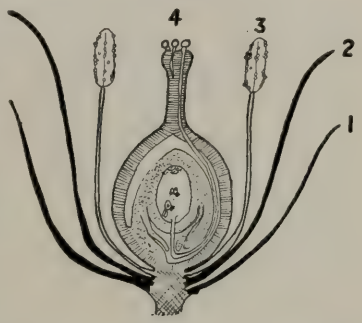

FIG. 89.—DIAGRAM OF A FLOWER.

Parts 1, 2, 3, 4—as in Fig. 86. Pollen grains (microspores) are present on the anthers. Three pollen grains are on the stigma. The middle one has begun to form a tube. The right one has formed a tube which has penetrated the ovule and discharged the two male nuclei into the female gametophyte. An enlarged view is shown in Fig. 90. (From Sinnott's Botany.)

by the fusion of the first sperm nucleus and endosperm nuclei develops into a mass of cells known as the *endosperm*, which surrounds the embryo in the corn seed and all monocotyledon seeds. Food is transported from the parent plant to the flower—to its ovary and through the funiculus to the ovule coats and through these to the seed. After the seed has developed to a certain point, the flower withers away, the ovule coats become hard and dry and impervious to water, and now the seed is prepared to pass long weeks during the fall and winter in a dormant condition. It will begin active life in the spring when it germinates.

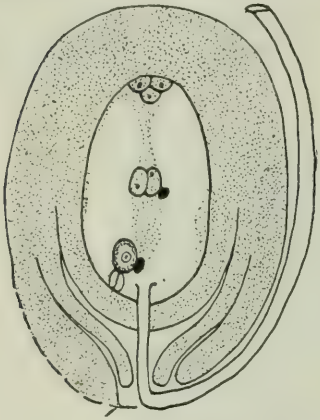

FIG. 90.—ENLARGED VIEW OF AN OVULE.

In the center is the female gametophyte with 8 nuclei. Three nuclei are opposite the micropyle; two near the center are the endosperm nuclei; the first sperm nucleus (in black) is uniting with these two; the second sperm nucleus is uniting with the egg nucleus near the micropyle. The 7th and 8th nuclei of the female gametophyte are at one side of the egg nucleus. The embryo will develop from the united egg-sperm nucleus; the endosperm will develop from the united endosperm-sperm nuclei. The shaded portions around the female gametophyte will form the seed coats. (From Sinnott's Botany.)

4. *Seeds.*—(*a*) MONOCOTYLEDON. On one face of the corn seed (Fig. 91) near the pointed end, is an oval-shaped area, under which is the embryo, and around which is the endosperm and seed coats. The parts can be understood best by examining a longitudinal section. On one side can now be seen the embryo in section. Toward the pointed end of the seed is the primary root or radicle of the embryo. At the other end is the plumule, which at the tip shows folded embryonic leaves. Between the embryonic leaves and root is the embryonic stem. The remainder is divided into two regions. Adjacent to the embryo is the single cotyledon, characteristic of monocotyledon plants. Outside of the cotyledon is the endosperm which is the food material for the young plant. It will be absorbed in the early development of the embryo. In monocotyledons the

endosperm is enlarged because it contains stored-up food for the embryo.

(*b*) DICOTYLEDON.—The lima bean seed (Fig. 92) has tough external seed coats which are the remains of the old integuments, and along one edge is a scar. This is the *hilum*, or place where the ovule was attached to the funiculus. At one end of this is a little pit, the micropyle through which the pollen tube entered. After soaking in water the seed coats are easily removed. Inside are found two large thick parts. These are the cotyledons or seed leaves and they are a part of the embryo. Sugar derived from the bean plant was transferred to these seed leaves and stored there as starch. At one end and between the cotyledons is the rest of the embryo. The body of it is called the *hypocotyl* or little stem. At the end of this is the *plumule* or embryonic leaves. The pointed tip of the hypocotyl develops into the root. The endosperm in dicotyledons is not prominent. Its function as a storehouse of reserve food

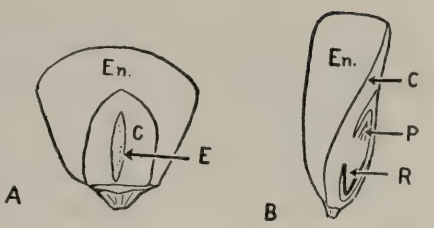

FIG. 91.—*A*, CORNSEED—FACE VIEW. *B*, VERTICAL SECTION OF CORN.

Around the seed is the seed coat. *En.*, Endosperm; *C.*, Cotyledon; *E*, Embryo; *P.*, Plumule and *R.*, Radicle of embryo. Corn is a monocotyledon.

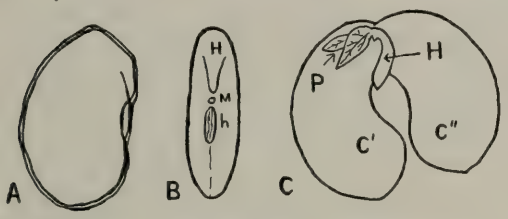

FIG. 92.—LIMA BEAN SEED, DICOTYLEDON.

A., Side view of seed; *B.*, Face view; *C.*, Seed opened to show embryo and the two cotyledons. *H.*, Hypocotyl and *P.*, Plumule of embryo; *M.*, Micropyle; *h.*, Hilum; *C'.*, and *C''.*, Cotyledons.

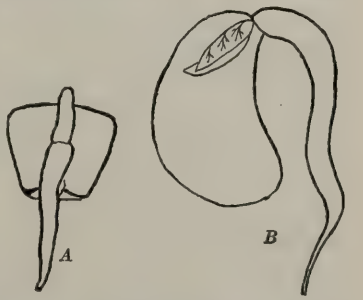

FIG. 93.—GERMINATION OF *A*, CORN AND *B*, LIMA BEAN.

Note early growth of root.

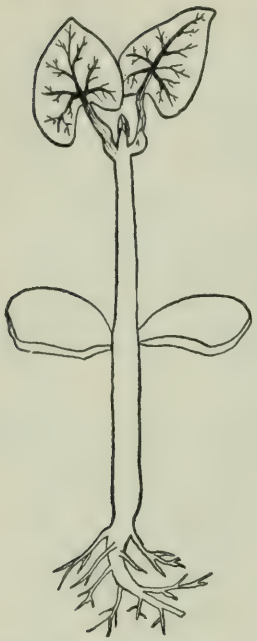

FIG. 94. — YOUNG LIMA BEAN PLANT, WITH ROOT SYSTEM AND YOUNG LEAVES.

The Cotyledons are above the earth. In the pea they remain in the earth.

for the growing embryo is taken over by the cotyledons. Seeds contain food in concentrated form and there is very little water in them. Because of the concentrated food, the seed has been utilized by man as his staple food supply. First in importance is wheat, then corn, rice, oats, rye, beans, peas, etc. Seeds contain proteins, starches, and some contain considerable oil, as is the case with cotton seed, corn and nuts.

5. *Germination.*—When seeds are surrounded by the proper temperature, moisture and air, they will germinate (Fig. 93). This means that the little embryo will sprout or start growing. Peas may be planted in cold soil while warm soils are necessary for corn. Most seeds have to undergo a period of rest and dryness before sprouting. Well-dried corn gives better crops than undried seed. It takes from a few days to two weeks for germination. The cotyledons of the pea remain in the earth, but those of the bean (Fig. 94) are raised above the earth. The cotyledon of the corn serves as an organ to transfer digested starch, i.e., sugar and proteins, from the endosperm to the growing embryo. The food stored in the cotyledons of the bean is also digested and transferred to the growing em-

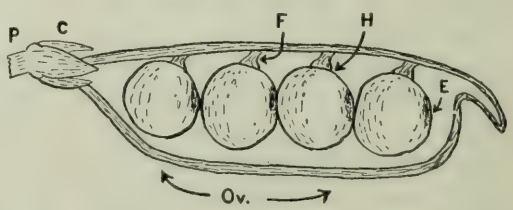

FIG. 95.—PEA POD, THE FRUIT OF THE PEA.

P., Old flower stalk; *C.*, Old calyx; *Ov.*, Ovary. At tip end is old style. Peas are enlarged ovules, etc.; *F.*, Funiculus, the stalk by which each pea is attached to the placenta; *H.*, Hilum; Embryos are located at *E.*

bryo plant. After the food of the cotyledons has been used up, the cotyledons wither and fall off. The digestion of stored food material as endosperm or cotyledons is accomplished by means of ferments or enzymes which are present in the seed. The conditions favorable to germination activate these enzymes. Although many plants may be propagated by various methods of vegetative reproduction, such as from pieces or "slips," most seed plants are propagated by seeds.

6. *Fruit.*—A fruit is a ripened ovary with its seeds. Fig. 95 is a diagram of pea fruit. An apple is the thick fleshy

FIG. 96.—CROSS-SECTION OF APPLE, A FRUIT.

Seeds are in the carpels (*C.*) of the pistil; The fleshy fruit is enlarged ovary (*Ov.*) and Receptacle (*P.*).

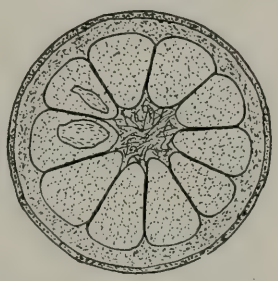

FIG. 97.—CROSS-SECTION OF ORANGE.

The locules of the ovary are filled with juicy pulp. Two seeds are shown. Oil is present in the outer part of the "skin."

wall of the receptacle which surrounded the ovary. (Fig. 96.) An orange is an expanded ovary whose locules become filled with pulp. (Fig. 97.) Most of the fruits with which we are familiar have had wild ancestors which have been domesticated and greatly improved by plant breeders. The little fruit of the rose called the rose apple is, after all, not so very far removed from our edible apples. We are all familiar with many berries, the improved fruit of wild plants.

7. *Distribution of Seeds.*—After the production of seeds, their distribution takes place. Any agency, which will scatter seeds and keep them from crowding, favors the possibility of developing mature plants. Animals feed on fruits for ex-

ample. In the digestive tract of the animal the fleshy part of the fruit is digested, but many of the seeds are unharmed and pass out with the feces, in all probability at places far distant from the place where the fruit was obtained. Some seeds have no fleshy coverings. Dry seeds, such as those of Bidens, have two prongs with sharp barbs which stick for a time to the hairy coats of animals and so are distributed. The seed of the dandelion or of the prickly lettuce is a veritable parachute. (Fig. 98*A*.) A slender thread extends from the seed to a parachute like tuft of hairs. Released

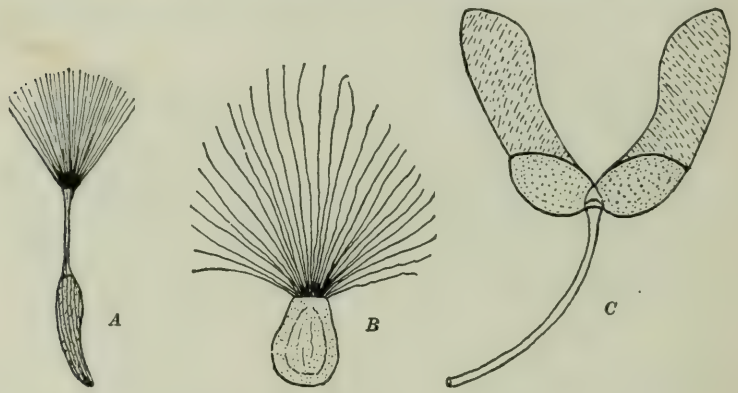

FIG. 98.—SEED DISPERSAL BY WIND.

A., Prickly lettuce; *B*., Milk weed; *C*., Maple.

from the plant the wind blows these little parachutes hither and thither and probably the seed is planted far from its place of origin. The seed of the milkweed (Fig. 98*B*) is somewhat similar in its action. The seed of the maple tree has wings (Fig. 98*C*). Nuts contain plant embryos. Certain animals feed on nuts. When eaten of course the embryos are destroyed. But the animals using this kind of food gather in supplies of nuts, and in the process of gathering and transportation many drop on the way and thus are distributed. There are also many interesting mechanical devices by which seeds are thrown from the seed pod.

Classification of Spermatophytes.—The Spermatophytes are the dominant group of the plant kingdom. The seed,

with its structures enabling it to withstand many adverse conditions, and the fruit with its methods of distribution, have all played no small part in this dominance of these plants. The almost indefinite growth of stem and root system has also contributed to this dominance. The seed plants are not only larger and more numerous, but also are more highly organized than the lower groups. They were once called *phanerogams* in contrast to the *cryptogams*. The cryptogams included the Pteridophytes, Bryophytes and Thallophytes. The word, phanerogam, meant plants whose methods or organs of reproduction were very evident. Such organs were supposed to be obscure in the cryptogams. At that time it was thought that the stamens and pistils were the sex organs. The pollen tube and embryo sac and the development of the same and fertilization were not at all understood. As a matter of fact, the sex organs are more simple and more easily seen in the so-called cryptogams.

FIG. 99.—PHOTOGRAPH OF A CYCAD, CYCAS CELEBICA.
N. Y. Botanical Gardens. (Photo by Fread.)

1. *Gymnosperms.*—There are two groups of the Spermatophytes, first the *Gymnosperms* and second, the *Angiosperms*. The Gymnosperms are the oldest seed plants. The ovule or megaspore is exposed to the air and is not inside an ovary, as in the Angiosperms. It is borne on a modified leaf or *megasporophyll*. The first Gymnosperms were derived from the ferns and remains of Gymnosperms have been found in

coal beds. They are divided into two groups: (*a*) the *Cycads*, and (*b*) the *Conifers*.

Cycads grow in warm climates (Fig. 99), and resemble tree ferns and palms in appearance with column-like trunks. The male and female sex organs are borne on cones which resemble somewhat the spore-bearing strobili of Lycopodium and Equisteum, although they are much larger. In the female cones ovules are borne along the edge of the megasporophylls, and in the male cone pollen grains are produced in sporangia on the microsporophylls. The pollen grain enters through a micropyle into a pollen chamber inside the ovule and adjacent to the megaspore. The pollen grain forms two ciliated spermatazoa which swim about in the fluid of the pollen chamber and eventually fertilize an egg when this develops from the embryo sac or megaspore. These free swimming sperm connect the Cycads with the Pteridophytes and Bryophytes which also possess free swimming sperm.

FIG. 100.—PHOTOGRAPH OF CONIFER FOREST.

Medicine Bow National Forest, Wyoming, 10,500 feet elevation. (Photo by Author.)

Pine trees (Figs. 100 and 100*A*), hemlocks, spruces, cedars, firs are Conifers. They usually possess a long straight trunk with longer radiating branches below and shorter ones toward the upper end, giving a cone-shaped effect to the whole tree. The leaves are usually green scales or needles. The trunk shows spring and summer wood and annual rings. The reproductive organs are also produced in cones, and as in the Cycads there are two kinds of cones, male and female, i.e., staminate and ovulate (Fig. 101). The staminate cones are small and do not live very long. Each is composed of lateral scales or microsporophylls which possess

microsporangia which produce pollen grains. Pollen is transferred to the ovules by the wind and for this purpose an immense amount of pollen is produced by a conifer forest in the spring. The ovulate cones in some species grow to a very large size. The cone scales or megasporophylls become hard and woody. Each cone scale produces two ovules surrounded by an integument and containing a nucellus inside of which is a megaspore mother cell. After a series of divisions a female gametophyte is organized here with two archegonia in each of which is an egg. The pollen grains, carried by the wind, fall on the upper surface of the edge of the megasporophylls and fall down to the micropyle in the integument and there two of them germinate and form pollen tubes. (Fig. 101.) Each pollen tube penetrates the nucellus and sends a male nucleus down to the egg cell in each archegonium. Two embryos are formed but one fails to develop. The integument changes into a seed coat and the micropyle closes. The seed (Fig. 101) is detached from the cone scale when the tree is shaken by the wind and being light in weight, it is carried some distance by the wind. Or it may be distributed by seed-eating mammals, such as squirrels. Conifers are ancient plants and there are not very many species of them. Nevertheless they flourish vigorously in the cooler regions of the earth,

FIG. 100A.—PHOTOGRAPH OF A CONIFER, BLUE COLORADO SPRUCE.

N. Y. Botanical Gardens. (Photo by Fread.)

both in the northern and southern belts of the temperate zones.

2. *Angiosperms.*—The second great group of the Spermatophytes is the Angiosperms. These plants form seeds inside the ovary. They constitute the most recent group of plants. They have become dominant over ferns and mosses in all sorts of terrestrial habitats. They even live in the

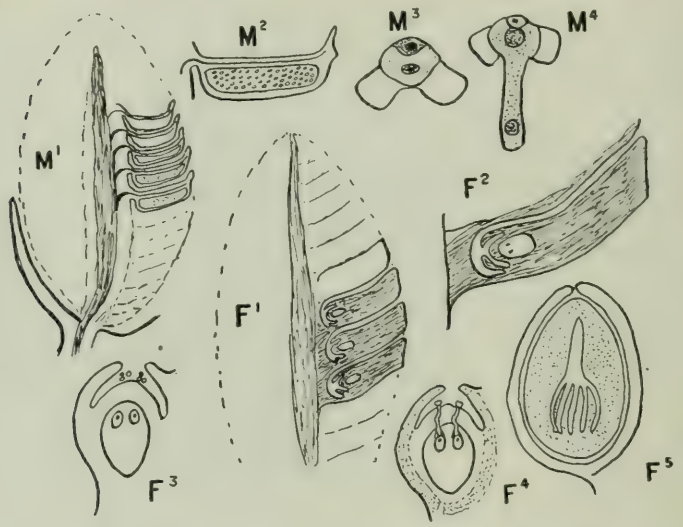

FIG. 101.—REPRODUCTION IN PINES (GYMNOSPERM).

M^1 Section of staminate cone with sporophylls; M^2, Sporophyll with pollen grains; M^3, Pollen grain with "wings"; and vegetative and tube nuclei; M^4, Tube nucleus divided into two sperm nuclei; F^1, Female or ovulate cone in section; F^2, One sporopyhll with ovule at base of scale; F^3, Mature female gametophyte with two archegonia and pollen grains; F^4, Two pollen tubes (male gametophytes) penetrating to archegonia. Only one develops. F^5, Mature seed. (From Sinnott's Botany.)

water, but there are very few species compared with the algae, which are better adapted to such an environment.

The Angiosperms are divided into two sub-groups: First, the *Dicotyledons.* These have two seed leaves or cotyledons; netted veined leaves; vascular system arranged in cylindrical form with xylem inside the cambium and phloem outside, and with the characteristic rings of wood in woody perennials and the floral parts usually in five or multiples

of five. Dicotyledons are divided into many families. Familiar examples are oak, apple, carrot, rose, pansies, beans and tomatoes. There are about 108,000 species.

The second group of the Angiosperms are the *Monocotyledons* which have about 25,000 species. They have only one seed leaf or cotyledon; parallel veined leaves; scattered fibrovascular bundles; floral parts in threes or multiples of three. They arose long ago from primitive Dicotyledons and have developed side by side with them.

With the exception of palms, most of them are herbs, which are of special value to mankind. All grains, wheat, rye, barley, rice, corn are Monocotyledons. Grasses, lilies and orchids are Monocotyledons. Underground bulbs are also to be found only in this group, the onion and the lily being the most familiar examples.

For classification of plants see Appendix A, page 573.

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Part III.—THE BIOLOGY OF ANIMALS

CHAPTER IX

PROTOZOA

The General Characteristics of Animals.—Animals, in contrast to plants, possess greater powers of locomotion. Their adjustments to external conditions are active, while those of plants are passive. Animals are provided with organs of locomotion. They possess a kind of protoplasm or organs more easily awakened into activity by external stimuli. The animal cell wall is soft and not at all like the cellulose wall of plant cells.

In plants the response to stimuli is slow, and in most it is a process of growth adjustment. Animals, on the other hand, are provided with quickly aroused sense organs, and nerves which rapidly convey impulses to the proper group of muscles whose action places the animal at once in the right relation to the changed external condition. Plant cells can manufacture proteins from carbohydrates plus simple nitrogen compounds. Animals cannot make proteins in this way but must be provided with proteins ready for use in order to live at all. The chief form of waste matter in plants is carbon dioxide and water. Animals excrete constantly nitrogenous wastes such as *urea*.

The *Animal Kingdom* consists of a number of distinct groups. In each group the animals therein included have a similar body plan. It is our problem here to begin with the simplest forms and show how from simple beginnings the more complex structures of the higher forms have gradually developed.

Phylum. I. The Protozoa

The protozoa are the simplest of all animals. The organism is either a single cell or an association of similar

cells. There are about 8500 species of protozoa and all are very small animals which can be seen well only with the aid of a microscope. There are four groups: *I. Rhizopoda; II. Mastigophora; III. Infusoria; IV. Sporozoa.*

Class I. The Rhizopoda.—The *Ameba* is a fresh-water form. (Fig. 102*A*.) It is about $\frac{1}{100}$ of an inch in diameter and resembles an irregular speck of jelly in motion. The protoplasm just under the surface is clear and colorless and is called the ectosarc. Inside this is the endosarc or granular protoplasm. Within the cell is the nucleus. At some point in the endosarc near the nucleus is a contractile vacuole. This forms as a minute space which increases in size. When near the surface film it contracts and discharges its contents to the outside. It serves as an organ of excretion. The Ameba may take in small grains of sand which it will soon eject. It exhibits some power of choice so far as food is concerned, and feeds on small algae and minute fragments of animal matter and on bacteria. There is no mouth, but material may be taken in at any point. The protoplasmic body simply flows around the food particles forming a gastric vacuole and then secretes digesting enzymes. After digestion the soluble food products are absorbed by the surrounding protoplasm, the circulation of which distributes the absorbed food. There is no respiratory system, but oxygen is absorbed through all parts of the surface. The absorbed food may be oxidized or it may be assimilated, i.e., made into more ameba protoplasm. We have already seen how excretion

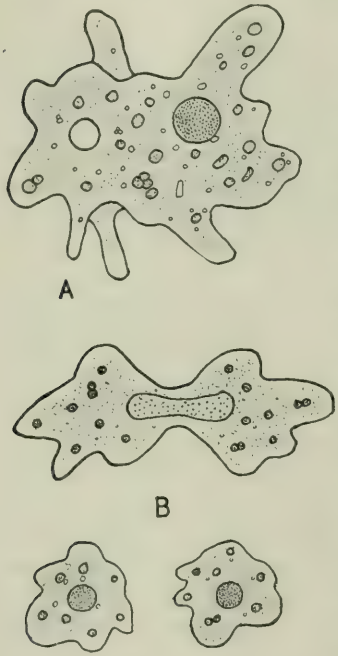

Fig. 102.

A, Diagram of amoeba. Nucleus toward right; Contractile vacuole to the left; *B*, Reproduction in Amoeba.

takes place. Undigested particles of food are discharged at any point of the periphery. This waste material is the feces. The enumeration of the above processes is but an enumeration of processes connected with metabolism in Ameba. Reproduction is by simple fission. (Fig. 102*B*.) The nucleus divides first; followed by the cytosome. After they are formed, the two daughter cells then grow. Each manufactures more protoplasm than it uses up and in time each daughter cell is as large as its parent was.

It is claimed also that the Ameba may reproduce by *sporulation*. In this process the animal assumes a spherical form. A thick wall is formed. The cell within divides and continues to divide until 500 or 600 small spore cells are formed within. When mature and conditions are favorable these escape and grow into normal-sized Amebae. In both cases reproduction is asexual. The Ameba possesses the property of irritability. It is sensitive to sudden changes in the external conditions. When touched with some object as a needle, it draws away. Apparently it " likes " to crawl on a surface, i.e., it " prefers " to be in contact with some object. If acid were added to one corner of a dish containing Amebae they would move to a part that is least acid. Ameba reacts negatively to extremes of heat and cold. It reacts negatively to intense light rays. The Ameba possesses not only irritability, but also conductivity and contractility. A stimulus produces a chemical change in the protoplasm and, as a result, a series of progressive changes is initiated, that is, an impulse traverses the Ameba's body. An impulse in higher animals travels over specialized protoplasm called *nerves*. An impulse is not a stimulus nor is it a sensation. It is a progressive physico-chemical change. That is about all we can say about it, but it produces a certain effect. The one that we are interested in now is contraction. The protoplasm contracts at certain points and relaxes at others. The surface tension at certain points of the Ameba's body decreases and the protoplasm streams out at that point, forming what are called pseudopodia or feet. For a short period the Ameba may move along in one direction by allowing the protoplasm of its body to flow forward from behind.

Are these movements of adjustment automatic or machine-like? If so, they are more complex than simple reactions in the purely physical world. For the Ameba exhibits some power of choice. As yet the position taken by extreme mechanists, that the reactions of the lower organisms are altogether similar to the attraction and repulsion that occur at the poles of an electric battery is not accepted by other biologists, who have conducted painstaking observations on the life of these simple forms.

FIG. 103.—ARCELLA.

The distinguishing characteristic of the Rhizopoda is the *pseudopodium*, that temporary organ of locomotion, which is merely a thread-like extension of protoplasm. Some Rhizopods live inside shells which they either secrete or fashion out of minute particles from their habitat. *Arcella* (Fig. 103) has a dome-shaped brown shell which it secretes. Its pseudopodia extend out through a circular opening on the flat surface of the shell. *Difflugia* (Fig. 104) has a more elongated conical-shaped shell made of particles of sand, etc. *Actinophrys* is a tiny spherical mass of vacuolated protoplasm with long pointed pseudopodia radiating out from it in all directions. Another group of Rhizopods, the *Radiolaria* (Fig. 105) have a chitinous shell immediately around the animal, and then a perforated shell of silica outside of this. The shells of such animals sink to the bottom of the sea after

FIG. 104.
DIFFLUGIA.

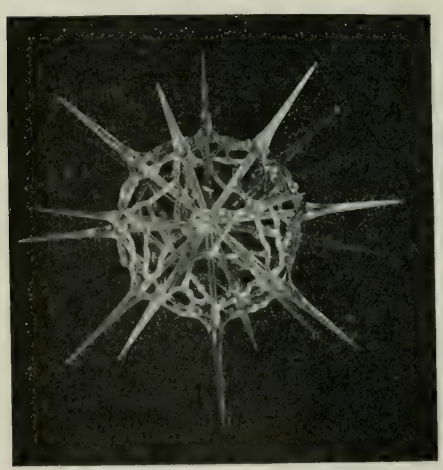

FIG. 105.—PHOTOGRAPH OF MODEL OF A RADIOLARIAN SKELETON.
(Amer. Mus. Nat. Hist.)

death. Accumulations of these for long periods of time form a hard flinty rock or quartz a thousand feet thick in places. The shells of another group are composed of calcium carbonate. Accumulations of these form gray chalk. In the Atlantic Ocean large areas are covered with a gray mud called *Globergerina Ooze*. This consists largely of innumerable rhizopod skeletons. The beds of chalk of the Cretaceous period were formed largely of the empty shells of these Foraminifera. Nummulistic limestone also originated in this way. The pyramids of Egypt are made of gigantic blocks of this stone. Some rhizopods are parasitic and cause disease.

Class II.—The Mastigophora.—The second group of Protozoa is the *Mastigophora*. *Euglena viridis* (Fig. 106) lives in fresh water. Botanists describe it as a plant because it is green. It is somewhat elongated and pointed at one end. The other end is rounded and from it projects a long whip-like process, the *flagellum*, which is an organ of locomotion. This flagellum extends from a slit-like opening back of which is a small tube which ends blindly. Contractile vacuoles discharge their contents into a reservoir near this end, where is also a small mass of red pigment called the eye spot or stigma, because it is supposed to be sensitive to light. There is one nucleus. There are many green, chlorophyll containing bodies in the cytoplasm. Utilizing the energy of the sun this type of chlorophyll can manufacture a carbohydrate substance, paramylum, from carbon dioxide and water. In this respect it is plant like, but the zoologist claims that it is an animal because it moves about so actively and also absorbs organic food through the surface of the body. It is very sensitive to light and reproduces by fission. When the water in which it lives dries up, the Euglena forms a spherical waterproof coat about itself, from which it escapes when favorable conditions again arise. Sometimes internal division occurs during this period of encystment.

Fig. 106.—Euglena.

Pandorina (Fig. 107) is a colonial form. It is spherical and consists of sixteen individuals, each with two flagella. *Volvox* (Fig. 108) is another colonial form. It is spherical and the interior of the sphere is fluid or gelatinous while the outer wall consists of some 10,000 cells connected with one another. Each cell has two flagella. Volvox may reproduce in two ways. First, some cells grow in size, divide a great many times and continue to do so in the interior of the sphere, each mass forming a small colony which breaks through the wall of the sphere to the outside. From other

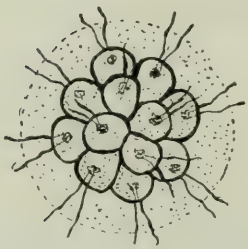

FIG. 107.—PANDORINA.
(After Conn.)

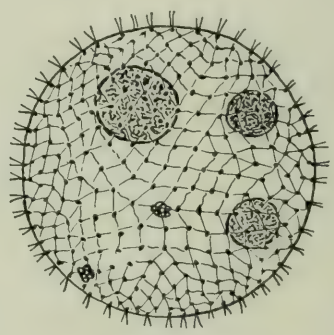

FIG. 108.—VOLVOX.
(After model A. M. N. H.)

cells both sperm and eggs are formed. After an egg is fertilized a new small colony develops.

These two colonial forms are described to indicate formation of more complex individuals by the association of similar cells. It will be noted that the association is in the form of a sphere. When higher organisms develop from the fertilized egg they form a spherical aggregation of cells at first similar to Pandorina and later to Volvox. This has more than superficial significance. It is an index of the path of nature in the production of higher organisms from the protozoa. However, in the colonial protozoan there is no specialization of function. All the cells are similar in structure and function. And we must call these colonies *Protozoa.*

African Sleeping Sickness is caused by *Trypanosoma* (Fig. 109) another member of this group. It is parasitic in the tsetse fly. (Fig. 110.) If an infected fly bites a person it thus introduces Trypanosomes into the blood of the human victim. The parasitic protozoan multiplies in the blood of the person and causes the disease.

FIG. 109.—TRYPANOSOME.
(From Hegner, College Zoology, after Calkins.)

FIG. 110.—TSETSE FLY.
(After Howard Bur. Ento., U. S. D. A.)

Class III.—The Infusoria.—The third group of the Protozoa is the *Infusoria* or *Ciliata*. A common example is *Paramecium* (Fig. 111*A*) which appears in hay infusions. Paramecium is a common fresh-water form and has been called the slipper animalcule because its shape is similar to that of a slipper with rounded heel and pointed toe. The blunt end appears to be the front of the animal. Near this end is the oral groove with its undulating membrane which extends obliquely back to about the middle. At the hinder end of the oral groove is the mouth which opens into the gullet—a canal extending a short distance. The surface of the body is covered with cilia. Each cilium is a minute protoplasmic process which has the power to move. The movement of the cilia is somewhat like the lashing or snapping of a whip. Similar ciliated cells occur throughout the animal kingdom. Due to the lashing movements of thousands of cilia, Paramecium is propelled rapidly through the water.

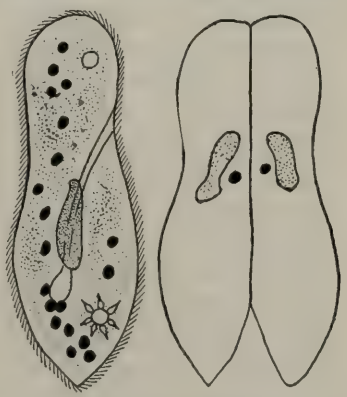

FIG. 111.—PARAMECIUM.
Single animal at left; To right, two animals conjugating.

Covering the *ectosarc* is a structureless membrane, the cuti-

cle or pellicle from which the cilia arise. Just under the cuticle are cavities containing a somewhat fluid-like substance. When irritated or stimulated in certain ways, Paramecium discharges from these cavities thread-like structures called *trichocysts*. These trichocysts probably carry with them some narcotizing substance. They are weapons with which the Paramecium defends itself. In other ciliates they may be used to capture food. Each Paramecium has a large and a small nucleus, the *meganucleus* and the *micronucleus*. There are two contractile *vacuoles* present. From each vacuole a series of canals radiates out into the protoplasm. By careful observation one may note the pulsation of the contractile vacuoles. First one pulsates, then the other. They discharge wastes. Particles of food are swallowed or swept into the gullet by the undulating membrane and pass into the protoplasm back of the gullet behind which food vacuoles are formed. A food vacuole is a little round space in the protoplasm surrounding the food particle. Enzymes are secreted by the surrounding protoplasm and digestion takes place. The food consists of minute animals or plants or fragments of the same. The protoplasm of the animal rotates round and round carrying the food vacuoles in its stream, and undigested food remains are discharged at the posterior end of the animal.

Paramecium can bend its body and squeeze through narrow places. It can move quickly forward and backward. As it moves forward, its body turns around the long axis. It exhibits reactions to stimuli, as does Ameba, but more rapidly and is apparently a more highly organized animal. Careful observation indicates that Paramecium reacts sometimes differently to the same stimulus. That is, the degree of response varies, or the quickness with which the response is made varies. About all that can be said now is that the " physiological state " of the organism varies. This is characteristic of all living things. Paramecium reproduces by binary fission. The animal divides in two by a constriction after new nuclei, gullet, and contractile vacuoles have appeared. This asexual reproduction may occur every day. If all the new individuals

lived and reproduced there would be many millions in one month.

At times two individuals come together (Fig. 111) and remain attached for a time. During this period the *macro* (mega) *nucleus* disintegrates. The micronucleus of each undergoes a series of divisions. Part of the micronuclear material of one individual passes over into the other animal and vice versa. This is a sort of fertilization. After fertilization the two separate and each organizes a macro- and micronucleus. Then for a number of generations each reproduces by binary fission. It has been found also that sometimes as in *P. aurelia* there is a reorganization of nuclear material within a single animal. This is called *endomixis*.

Fig. 112.—Stentor.

Infusoria are Protozoa whose locomotion is by means of cilia. Another example besides Paramecium is *Stentor* (Fig. 112), which is trumpet-shaped when attached and at rest. The nucleus is sometimes like a line of beads. *Vorticella* (Fig. 113) has a bell-like body attached at the end of a stalk, the lower end of which is attached to some object. The stalk contains within it a contractile thread of protoplasm and when contracting this stalk winds up with great rapidity like a spring. *Stylonychia* (Fig. 114), has not only fine cilia, but a few larger processes by means of which it moves or creeps along some submerged object.

Fig. 113.—Vorticella.

Class IV.—The Sporozoa.—The Sporozoa (Fig. 115) constitute the fourth group of Protozoa which have no organs of locomotion, but are parasitic in more complex animals. They reproduce by spores. One species, *Porospora gigantea*, found in the intestine of the lobster, is sometimes 15 mm. long and is one of the largest Protozoans. Malaria is caused by a Sporozoan. For a long time it was thought that malaria was caused by breathing in the damp air or miasmas from swampy regions. In 1891

Laveran stated that he believed malaria was transmitted from one diseased person to another by some insect which sucked blood. Major Ronald Ross, an English army surgeon, proved this in 1899. The insect responsible for the transmission of malaria was found to be the female *Anopheles mosquito.* (Fig. 116.) After it has sucked blood from a person who has malaria it may visit some uninfected person whom it stabs with its piercing mouth-parts and injects a little saliva from its salivary glands to prevent immediate coagulation of the blood. The mosquito's saliva contains a few malarial parasites, and in this manner these are transmitted to the other person's blood system. The parasites of the malarial sporozoan at once invade the red blood cells. There they reproduce by sporulation and a great many small spores in due time escape from the corpuscle. Not only does this destroy the corpuscle, but it also releases into the blood certain toxins or poisons. The liberated spores enter other corpuscles, more are infected this time, later sporulate and still later are liberated into the blood stream along with their toxins. This may continue indefinitely with a rapid increase in infected blood cells. The chill in malaria is either due to the destruction of great numbers of corpuscles or the liberation of the toxins. The body at once mobilizes its defenses and unassisted may overcome the invading host. If the blood of the victim, however, contains quinine, then the parasites are killed as they emerge from the corpuscle. So quinine

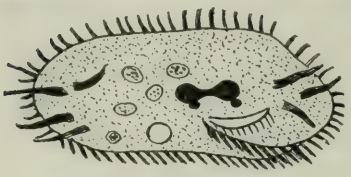

Fig. 114.—Stylonychia.

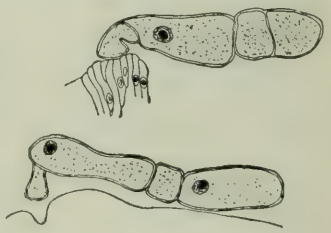

Fig. 115.—Gregarine from intestine of meal worm (larva of tenebrio beetle).

Fig. 116.

To the left—Anopheles mosquito. To the right—Culex mosquito. (From American Museum of Natural History.)

is the specific drug used in such cases. When a female Anopheles bites a malarial patient it sucks the sporozoa into its own blood stream. In the body of the mosquito it undergoes another phase in its life history, an important part of which is sexual reproduction. The use of quinine is only partially successful as compared with prophylactic measures. This means prevention and malaria may be prevented by getting rid of the mosquito.

Yellow fever is caused by a parasite in the body of another mosquito, now called the Yellow Fever Mosquito, *Stegomyia* (Fig. 117.) The United States was able to construct the Panama Canal only after Stegomyia was conquered. When the French under DeLesseps tried to build the canal, the whole project was a dismal failure due largely to the prevalence of yellow fever. After 22,000 persons died, the French abandoned the project. At that time the relation between yellow fever and the stegomyia mosquito was not known. To-day the Canal Zone is described as a health resort, but in order to bring this about it was necessary to understand the relationship of the mosquito to this disease. It was done by experimentation in which real heroes were willing to be bitten by Stegomyia mosquitoes that were thought to be infected. In the course of this work Dr. Jesse Lazear, a young American, contracted the disease and died. Fortunately others acquiring the disease in this experiment did not die, but were able to show the relationship between the mosquito and the disease. The American Yellow Fever Commission began work in 1898 at Havana, Cuba, at the close of the Spanish-American War. In seven months Havana was free of yellow fever for the first time in 140 years. In 1878, an epidemic of yellow fever in our own Southern States caused 16,000 deaths and an economic loss of about $100,000,000. A few years after

FIG. 117.—STEGOMYIA MOSQUITO.

(Bur. Ento., U. S. D. A.)

the pioneer work of the Yellow Fever Commission at Havana, General William C. Gorgas in about a year's time abolished yellow fever from the Panama Canal Zone. He later stated that it was practically possible to rid the whole earth of this dread disease.

A certain sporozoan parasite causes Texas Fever in cattle. It is introduced into the animal by a biting blood-sucking insect called a tick. For thirty years Texas fever caused an annual loss of millions of dollars in our own Southwest. Experiments indicated that cattle could be freed from these insects by "dipping" the animals in a solution of an arsenic compound. Great tanks of this solution are prepared, the cattle are made to swim through, and thus the ticks are killed. In 1923 over 3,000,000 cattle were thus treated and saved.

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CHAPTER X

PHYLUM II. PORIFERA

In the higher animals specialization is the rule. We find different tissues and different organs each with special function. Organization is present in all, but specialization is only true of the higher forms. Animal organisms consisting of many cells, some of which are specialized for one function and other groups for other functions, are called *Metazoa.* The *Colonial Protozoa* are transitional forms between the strictly unicellular and the multicellular. The following phyla are Metazoa.

The *Porifera,* or Sponges, are the simplest Metazoa. They are multicellular aggregations of cells which show a certain degree of specialization. There are about 2500 species. Some are quite simple but others are very complicated. The simple form described below may be considered a unit. In the more complicated types this unit plan is multiplied, resulting in a large organism, all the units of which are interconnected. *Grantia* (Fig. 118) is a simple form and is common along the New England coast. It is flask- or urn-shaped, yellowish-brown in color, and about one-half inch in length. The lower end is attached to a submerged piece of wood or shell. Sponges do not move about. At the free end is the mouth or *osculum.* This leads into a cavity called the *cloaca.* Around this cavity is the body of the sponge. The body wall consists of living cells on the outer and inner surfaces and in the wall between. In the body wall is also a structureless substance called *mesogloea.* Imbedded in this is the skeleton of the sponge.

FIG. 118.—GRANTIA, A SPONGE.

It consists of minute calcareous rods called *spicules*. These may be short or long straight rods, triradiate or "T" shaped rods. In the mesogloea are also found ameboid wandering cells. The outer wall is marked by pores leading into chambers or canals in the wall. The universal presence of these pores gives the name *Porifera* or pore-bearing animals. The canals into which the external pores lead are called *incurrent canals*. (Fig. 119.) These are lined with flat epithelial cells and are blind at their inner ends. Narrow passageways, called *prosopyles*, lead from the incurrent canals into excurrent canals which alternate with the incurrent canals. These excurrent canals are blind at their outer ends. They open into the gastric cavity. They are lined with epithelial cells that have collars at their free ends, and also with a single long flagellum. Each of these cells resembles a flagellate protozoan. It is the movement of the flagella that causes water currents to pass from without first into the incurrent canals, then through the prosopyles into the excurrent canals and thence into the gastric cavity and out through the osculum. Minute organisms in the seawater as they pass the excurrent canals are taken for food.

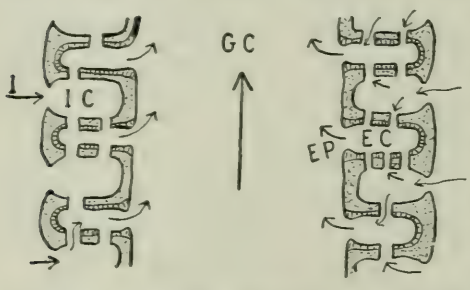

FIG. 119.—PLAN OF ANATOMY OF A SIMPLE SPONGE.

I., Incurrent pore; *I. C.*, Incurrent canal; *E. C.*, Excurrent canal; *E. P.*, Excurrent pore; *G. C.*, Gastric cavity. Arrows indicate direction of water. Central arrow points toward osculum. (Modified from McMurrick, "Invertebrate Morphology.")

Digestion occurs within these cells. Digested food is passed from these cells to other cells of the body. Excretion and respiration take place through the body wall. Reproduction is asexual and sexual. Asexual buds arise near the base of the sponge. These may continue to grow there and in this way clusters of individuals are formed. If such indi-

viduals became connected by a series of canals a more complex sponge would be the result. The more complex sponges are aggregations of a great many units similar to Grantia, but all connected by a system of canals. Eggs and sperm are formed in the mesogloea, but not at the same time. The egg takes up a position near one of the excurrent canals. Sperm from other sponges of the same species are brought in with the current, and as they pass near, one fertilizes the egg. The bath sponge (Fig. 120) is the skeleton of the

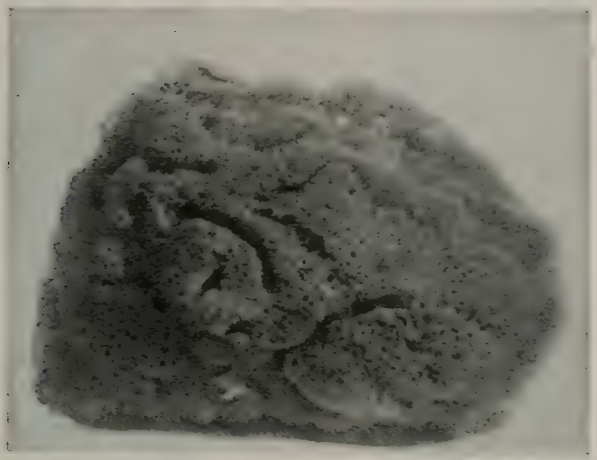

FIG. 120.—PHOTOGRAPH OF EUSPONGIA, THE BATH SPONGE

This is the spongin skeleton of the animal.

Euspongia. The material is a nitrogenous compound of soft fibrous texture. It is called *spongin* and is similar in composition to silk. Other sponges contain siliceous spicules in addition to the spongin. In still others the skeleton is siliceous alone. *Euplectella* or Venus' Flower Basket (Fig. 121), found chiefly in the Philippine Islands, furnishes a large example of this sort of skeleton. Hyalonema, (Fig. 122), the glass rope sponge, is another example. Some sponges of simple type grow in fresh water but most of them live in the sea.

In 1920–22 over two million pounds of sponges per year were placed on the market with a value of over $3,000,000.

The Mediterranean continues to be the principal source of supply. The Bahama Islands and the United States are close seconds. The most desirable sponges for general purposes are spheroidal or cake-shaped of medium size and soft in texture. The finest and softest are the Turkey cup sponges from the Mediterranean. Large specimens have sold for $50 each. Sponges can be raised by taking advan-

FIG. 121.—PHOTOGRAPH OF SKELETON OF EUPLECTELLA, VENUS FLOWER BASKET.

FIG. 122.—PHOTOGRAPH OF SKELETON OF HYALONEMA, THE GLASS ROPE SPONGE.

tage of their powers of regeneration. It has been found that a piece of a living sponge will in a few years grow to marketable size. This is a vegetative form of reproduction. The method followed in this type of culture is as follows: pieces containing about eight cubic inches of material are cut from a living sponge. These small pieces are fastened by means of aluminum wire to cement disks about one inch thick and ten inches in diameter. These

pieces are then " planted " on favorable bottoms. Sponges are being thus grown in the Bahama Islands.

When sponges occur in shallow waters they can be dislodged by the fisherman who wades in up to his neck and kicks the sponges free with his toes. Diving for sponges has been followed from ancient times in the Mediterranean. Diving suits have been used in the Mediterranean since 1866 and in Florida since 1905. The Florida sponge fisheries are conducted mostly by Greeks who have migrated from the Mediterranean to this country. Various methods of preparing sponges for the market are followed. Very often the sponges are placed on deck and then trampled over by the bare feet of the crew. This kills the animals. They are then strung on lines and hung overside until all the living cells decay, when the decayed tissue is thoroughly and completely washed out in tubs on deck. They are then taken ashore where after trimming and drying they are packed in standard weight bales.

Sponges are not preyed upon by other marine animals because of the skeleton and also because they excrete noxious substances. Certain hermit crabs surround their shells with distasteful sponges and so gain protection for themselves. Oysters are starved by sponge growths on the shells. The sponges take in all the available food. It is claimed that flint rocks have been produced in part by sponges which abstract the silica of seawater in forming their skeletons. Porifera have sometimes been called Parazoa. The word indicates that they are an offshoot from the early Metazoa and not in the main line of evolution.

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CHAPTER XI

PHYLUM III. COELENTERATA

In this phylum are placed corals, jellyfishes and many other kinds of aquatic and marine Metazoa. Six types will be presented.

I. Hydra. (*a*) *Morphology.*—The first of these is the genus *Hydra,* which contains a number of species found in fresh water. *Hydra oligactis* (Fig. 123) is brown in color and *Hydra viridis* is green. Hydras live in fresh water. The animal is tubular in form and about 5 mm. in length. The basal end is attached to some aquatic plant. The free end is provided with a circle of from 6 to 10 tentacles. It can lengthen its body considerably or contract it into a short thick lump. At the free end is the mouth which is the entrance to the gastric cavity. The body wall and tentacles consist of two layers of cells (Fig. 124), hence it is a *diploblastic animal.* The cells of both layers are epithelial. The outer layer is called *ectoderm* and the inner *endoderm.* Between these two layers is a thin, jelly-like, acellular layer called *mesogloea* (mid-glue). Outside the ectoderm is a thin acellular cuticle. The endoderm cells are somewhat larger than those of the ectoderm. In *Hydra viridis* the endoderm cells contain bright green bodies of chlorophyll

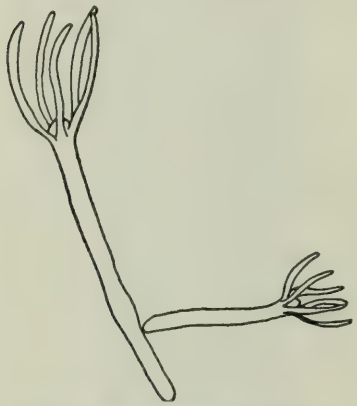

FIG. 123.—SKETCH OF HYDRA.

To the right is a young animal still attached to its parent.

(chromatophores). It is thought that these are simple algae symbiotically associated with the Hydra. The endoderm cells may contain one or two vacuoles (cf. Protozoa). Undigested food particles may also be found in the endoderm cells. The internal free ends of the endoderm cells may have from one to two ameboid like pseudopodia. Different kinds of ectoderm cells are present. The larger cells are epithelial and the inner ends of some of these are prolonged into processes which extend at right angles to the body of the cell. (Fig. 125.) Such cells are highly contractile and they are functionally muscular. Interstitial cells lie between the tapering inner ends of the ectoderm cells. Some of them are *cnidoblasts*. They produce special stinging structures called *nematocysts*. One type of cnidoblast cell (Fig. 126) contains a nucleus and a pear-shaped nematocyst, inside of which is an inverted, slender, coiled tube with three prongs or barbs at its base. Extending from the free surface is a small, trigger-like process the *cnidocil*. When this is stimulated the nematocyst explodes. In this process the coiled thread shoots out into the water, paralyzing such small animals which the Hydra can then pull into its mouth by the tentacles. Some investigators have described a fine network-like nervous system in the ectoderm. Sensory cells in the ectoderm connect with this nerve net. The nerves are supposed to connect the muscular-like internal process of the ectoderm cells. A reflex mechanism is thus provided, consisting of three elements; 1st, the *receptor* or sensory external end; 2d, the *adjustor* or nerve part conducting the impulse; and 3d, the *effector* or muscle part by which contraction takes place. The tentacles contain great numbers of stinging cells.

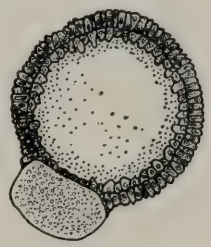

FIG. 124.—DIAGRAM OF A CROSS-SECTION OF HYDRA.

The outer cells are ectoderm; inner cells, endoderm, inside the latter is the gastric cavity. At the side is a section through a testis.

FIG. 125.—AN ECTODERMAL CELL OF HYDRA WITH AN INTERNAL MUSCULAR PROCESS.

(*b*) *Physiology.*—Hydra lives on small aquatic animals which come within range of its ever-moving tentacles. It can bend its body in all directions in its search for food. By means of the tentacles the food is brought to the mouth and swallowed. Digestion may occur within the gastric cavity. Food particles may also be taken directly into the endoderm cells, thus recalling protozoan conditions. The digested food is passed (circulation) to adjacent cells. Any cell may respire and excrete. The presence of vacuoles suggests a possible excretory function.

FIG. 126.—CNIDOBLAST CELL OF HYDRA WITH ITS EVERTED NEMATOCYST

To the left of the cell at the free end is the "trigger." (Modified from Hegner, College Zoology, after Schneider.)

REPRODUCTION.—Budding is common. A slight growth appears on the body wall and this becomes a tube. Tentacles appear at the free end, a mouth breaks through. It soon becomes a young Hydra (Fig. 123), connected for a time with the parent body. Finally it breaks away and shortly settles down as an independent animal. Hydra also reproduces sexually. Certain interstitial cells near the free end develop into a testis (Figs. 124 and 127*T*.) This is a sac within which numerous sperm cells form. Each sperm is a free-swimming cell consisting of a headpiece containing a nucleus and a single, long, motile flagellum. The sperm escape through an opening in the testis wall. Other interstitial cells (Fig. 127) near the base develop into an ovary. This is also a sac inside of which a large egg

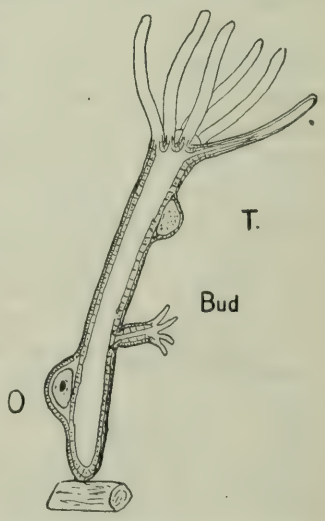

FIG. 127.—HYDRA WITH TESTIS, *T*; OVARY, *O*; AND A BUDDING HYDRA (BUD).

(In part after Hegner, College Zoology.)

cell is developed. As it increases in size it ruptures the ovarian sac and protruding into the water is exposed for fertilization.

DEVELOPMENT.—The fertilized egg divides into two, four, eight, sixteen, or more cells. At one stage there is a spherical mass of cells sometimes called a *morula* resembling the colonial protozoan, Pandorina. Later as the cells increase in number a cavity appears and the young embryo resembles a hollow ball, the wall consisting of a single layer of cells. This is the *Blastula stage* (Fig. 128) and resembles the colonial protozoan, Volvox. By ingrowth of cells at one point a two-layered (*diploblastic*) embryo is formed. The outer layer is the ectoderm and inside this is the endoderm in the form of a tube (*coelenteron*—hollow intestine). The mouth (and also anal) opening is at the point where ectoderm meets endoderm. This stage is called the *gastrula* (Fig. 129.) The endoderm cells now grow close to the ectoderm with the mesogloea in between. The tentacles and other specialized structures of the Hydra appear. On the whole Hydra is but a specialized gastrula. The fertilized egg suggests a unicellular protozoan ancestry and the gastrula stage, a volvox-like ancestry. The body plan of Hydra is in its main outline the body plan of all coelenterates. Hydra very rarely reproduces by fission.

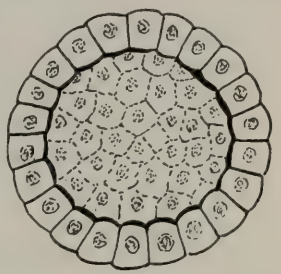

FIG. 128.—DIAGRAM OF BLASTULA OF AN ECHINODERM.

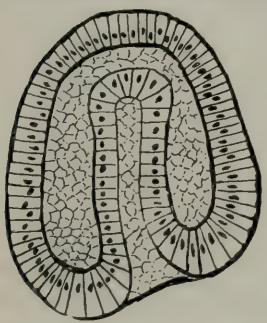

FIG. 129.—DIAGRAM OF GASTRULA OF AN ECHINODERM.

There are over 4000 species of Coelenterates and many kinds of body plans. Nevertheless they all agree in fundamental points with that of the Hydra. The Coelenterate having attained the gastrula stage in evolution, developed it along many special lines, but it still remains a gastrula plan.

The higher animals (see Figs. 128 and 129) pass through this stage on the way to a higher type of bodily structure.

Regeneration.—Hydra also exhibits great powers of regeneration. This was first discovered by Trembley in 1744. If Hydra is cut into two, three, four or more pieces, each piece develops into a new Hydra. Small pieces $\frac{1}{6}$ mm. in length may develop into complete Hydras. This is a sort of a vegetative reproduction similar to the formation of a complete plant from a small part.

Adjustment.—Hydra can change its position by slowly gliding along on its base. It can bend over, release its basal attachment, and move along on its tentacles. Also, it can bend over, attach its tentacles, release its base, then bend over again and by a series of somersaults move along. On the whole it successfully adjusts itself to its environment.

II. An Obelia Colony (Fig. 130) is a colonial Coelenterate which lives in seawater attached to stones or submerged wood or to marine plants. A central stem-like part is present to which branches are attached. Many of these branches end in hydra-like structures called *hydranths*. All other branches end in reproductive individuals called *gonangia*. The soft parts of the colony are protected by a chitinous sheath called the *perisarc*. This possesses rings at places and, near the ends of branches bearing hydranths, is in the forms of cups called *hydrothecae*. The soft part of the stem and branches form the *coenosarc*. The gastric cavity of each hydranth communicates with a cavity in each branch and this with a similar cavity in the main stem so that all the vegetative members of the colony are connected by a common vascular cavity. The coenosarc consists of two layers of cells, outer ectoderm and inner endoderm. Each hydranth is also composed of ectoderm and endoderm. The mouth is in the center of the mound-like hypostome. Around the base of the hypostome are about thirty tentacles. The tentacles possess a great many nematocysts. The Obelia colony does not reproduce sexually. The gonangia (Fig. 130) arise as buds from the ends of certain branches. Each has a central axis called the *blastostyle*. This produces *medusoids* by budding. (Fig. 131.) A sac-like covering

over the whole structure is the *gonotheca*. The medusoids when mature become detached from the blastostyle and escape into the water through the free end of the gonan-

FIG. 130.—PHOTOGRAPH OF MODEL OF PORTION OF OBELIA.

At the left below is an expanded hydranth; opposite this is a gonangium with gonothecal sac, central blastostyle and budding medusoids. (Courtesy Amer. Mus. Nat. Hist.)

gium. The medusoids are minute, umbrella-shaped bodies. Around the periphery is a fringe of tentacles. Hanging down from the center from the lower surface is the tube-

shaped *manubrium* at the end of which is the mouth opening. The gastric cavity extends from the mouth through the manubrium into four radial canals which extend at right angles from each other from the inner end of the manubrium to the periphery of the umbrella-shaped body.

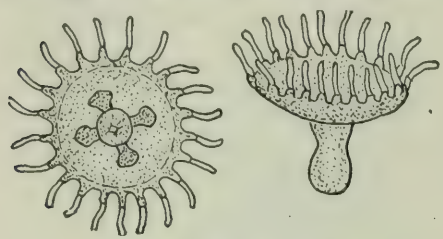

Fig. 131.

To the left surface view of medusoid of Obelia. To the right lateral view of medusoid with Manubrium everted.

These medusoids are free swimming. They bear sex organs. Some individuals produce sperm and others produce eggs. The reproductive organs are located along the radial canals. Sperm are discharged into the water and carried to the eggs. The fertilized egg undergoes cleavage into two, four, eight, sixteen-cell stages, and a *blastula* and *gastrula* are formed. By further development the latter becomes a new colony. Since the colony is composed of hydra-like members, all part of one connected system, it is called a *hydroid colony*. Alternation of generations is present. The Hydroid colony is the asexual generation and the medusoids constitute the sexual generation. Alternation of generations, which is so characteristic of the Bryophytes, Pteridophytes and Spermatophytes is not so common in the animal kingdom. It is well represented among the Coelenterates.

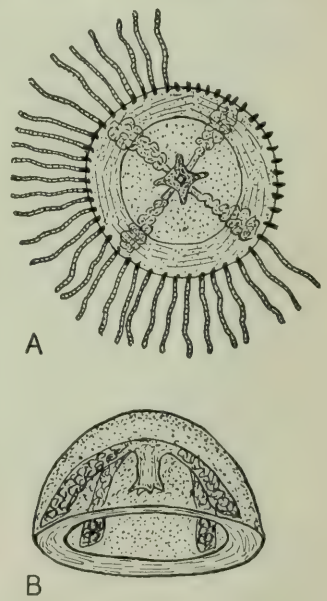

Fig. 132.

A, Ventral view of Gonionemus; *B*, Lateral view without tentacles.

III.—Gonionemus. (Fig. 132.)—This jelly fish, about a half inch in diameter, looks

like a plano-convex mass of jelly. The convex surface is the *exumbrellar surface* while underneath is the *subumbrellar surface.* Beneath the exumbrellar surface is the subumbrellar cavity. A flat narrow shelf with a large central opening called the *velum* partially encloses this cavity. When the body is relaxed water fills the cavity through the opening in the velum. When the body contracts it forces this water out through the velum opening, thus propelling the animal. Gonionemus swims by a series of such acts. Around the margin of the bell are a number of tentacles, and near the base of the tentacles are Statocysts, organs of equilibrium. Hanging down in the subumbrellar cavity is a stalk-like process —the *manubrium.* This leads into the gastric cavity in the jelly-like substance between the exumbrellar and subumbrellar surface. Four radial canals extend at right angles from the gastric cavity out to the margin of the *medusa.* The gastric cavity and the four radial canals are lined with endoderm. All superficial surfaces are covered with ectoderm. The mass of the animal is the jelly-like mesogloea. A fine circumferential canal runs around the peripheral margin of the animal and the radial canals connect with this. The general structural plan is similar to that of Hydra. The reproductive organs (*gonads*) are located on the under side of the radial canals. The sexes are separate (*dioecious*). Eggs and sperm are discharged into the water where fertilization takes place. The early development is similar to that of an Obelia medusoid. A hydra-like larva is probably present. There is some evidence that other hydra-like members form by budding from the first member. A sort of hydroid colony is formed from which other Gonionemus medusae originate.

IV.—Aurelia (Fig. 133) is a type common along the North Atlantic coast. It is saucer-like in form and about 2 to 4 inches in diameter. The margin is divided into eight parts by notches. Sense organs of equilibrium (*tentaculocysts*) are located in these notches. Apparently organs of chemical sense (taste and smell) are located here also. A fringe of tentacles borders the periphery. Four

oral lobes extend down from the mouth. A short gullet is present leading into a rectangular stomach from which four pouches extend at right angles to one another. Many radiating and branching canals run out from the stomach to a circumferential canal located at the periphery of the animal. The gonads are located on the floor of the stomach pouches. The animal is dioecious. Eggs or sperm pass into the stomach and out of the gullet into the seawater. Eggs are caught and fertilized in the oral arms. The fertilized egg develops into a free swimming larva which later becomes attached and leads a sedentary life. After a unique asexual process, free swimming Aurelias are again formed. This sedentary stage is comparable to a hydroid colony. Only the free swimming medusa stage is present in some forms similar to Aurelia.

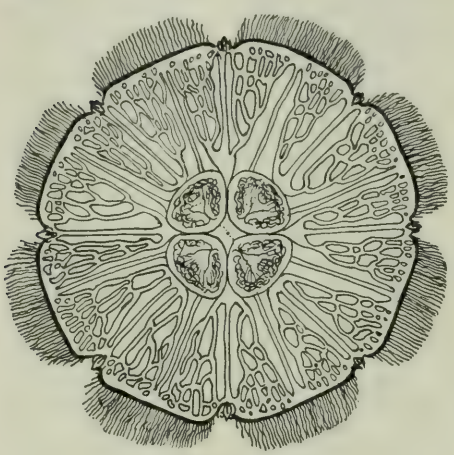

FIG. 133.—AURELIA.
(U. S. Bur. Fisheries.)

V.—Metridium (Fig. 134), a sea anemone, is found along our coast. It is a tubular sedentary animal about two inches long. It is attached to rocks or wharf pilings. The free end is crowned by many tentacles. In the center of the free end is the slit-like mouth. At each end of the mouth is a groove (*siphonoglyph*) provided with cilia. Water passes down one groove and up and out by

FIG. 134.—METRIDIUM.

the other groove. The gullet, a flattened cavity, extends down toward the base. Between the gullet wall and body wall is a space, the coelenteron. This is divided into cavities by radial vertical double *mesenteries* or *septa* (partitions). Perforations in the mesenteries put all the cavities into communication with one another. At the free end just below the tentacles is a ring of circular muscle (*sphincter*) whose contraction closes the mouth tightly. When this happens, due to some sudden external disturbance (stimulus) the tentacles retract also. Longitudinal muscles, whose contraction causes the shortening of the animal, are found on one side of the mesenteries. Metridium reproduces by budding and gonads also occur in the radial cavities. The lower end of the gullet ends in a cavity which connects with the radial cavities. The body wall contains sensory cells and nematocysts. Well-developed muscle occurs in the mesenteries which form a sort of skeleton for the animals. The radial cavities are filled with a nutritive fluid.

FIG. 135.—SIDERASTREA RADIANS.
(Photograph of model at Amer. Mus. Nat. Hist.)

VI.—Astrangia (Fig. 135) is a coral found along the North Atlantic coast. It is a colony of individuals each of which resembles in general a sea-anemone. At the base of each individual is a substratum of calcium carbonate, the coral, which is secreted by the animal. The colony spreads by budding.

Classification.—There are four *classes* of Coelenterata.

I. Hydrozoa, to which Hydra, Obelia, Gonionemus, the Millepora corals and other hydroids belong.

II. The Scyphomedusae, to which Aurelia and the large jelly fish belong.

III. The Actinozoa, to which the sea-anemones and true corals belong.

IV. The Ctenophora or Comb jellies. These are somewhat globular jelly-like very transparent animals. They are free swimming. Locomotion is accomplished by eight rows of comb-like swimming organs on the surface of the body.

Summary.—Coelenterata are Metazoa with radial symmetry; the body consists of two layers, the ectoderm and endoderm enclosing one gastric cavity; between the ectoderm and endoderm is a structureless layer, the mesogloea. Asexual reproduction takes place by budding, often producing colonies; sexual reproduction also occurs. They are aquatic and mostly marine; free swimming or sedentary. Alternation of generations occurs between the free swimming form and the sedentary form which is sometimes called the polyp to distinguish it from the free swimming medusa.

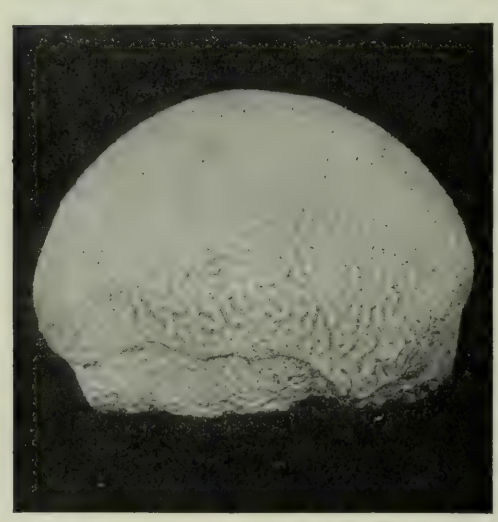

Fig. 136.—Brain coral—Meandrina.

Hydractinia is a colonial form living on the surface of a mollusc shell which in turn is inhabited by a (hermit) crab. From a layer on the shell originate two types of individuals; 1st, the nutritive members which resemble hydras, and 2d, the reproductive members. All individuals are connected by communicating canals in the basal layer. This association between the Hydractinia and hermit crab is a case of *commensalism*. The crab is protected by the coelenterate colony, its home having the general appearance of seaweed. It serves the hydroids in turn by carrying these about from one good feeding ground to another. Sea-

anemones also live on gastropod shells inhabited by hermit crabs. Commensalism is further illustrated by small fish which hide in the gastric cavity of certain large anemones found in the Great Barrier Reef of Australia. In the blue coral a certain worm inhabits small cavities in the coral. On this account it was once thought that the coral substratum had been made by the worm.

Coral polyps build coral reefs and atolls. Colonies of corals are extended by budding. The great variety of form of the compound corals (Figs. 136 and 137) is due to the different methods of budding. There are two kinds of coral reefs. The shore or fringe reef is formed on the sea bottom near the land. There is no direct channel from the outer edge of the reef and land although there are many pools and small channels in which a great variety of marine animals live. A barrier reef (Fig. 138) is separated from the shore by a wide channel. The Great Barrier Reef of Australia is over a thousand miles long with a channel between thirty to sixty miles wide and from 50 to 175 feet deep.

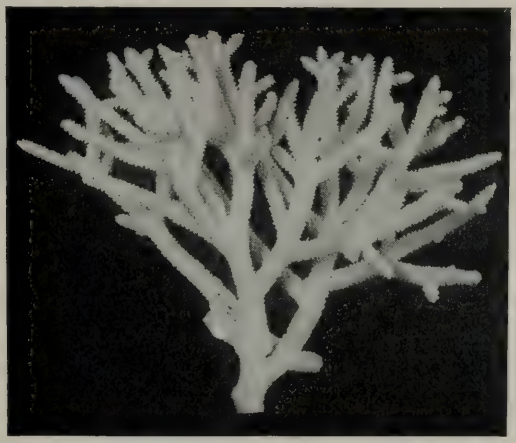

Fig. 137.—Staghorn-coral Madrepora.

An *atoll* is an island in the form of a ring with a lagoon inside. The waters of the lagoon are protected. The atoll is formed according to Darwin by coral colonies at the apex of some subsiding volcanic cone. Growth continues until a small patch of reef extends above the low-water mark.

Coral reefs have existed for untold ages. In the ancient

Cambrian Age the rocks show clear-cut evidence of their existence, at that time.

(Courtesy, Amer. Mus. Nat. Hist.)

FIG. 138.—PHOTOGRAPH OF GREAT BARRIER REEF OF AUSTRALIA.

The precious coral of commerce is *Corallium rubrum* (Fig. 139), the red coral, which is found only in the Mediterranean. Theophrastus, writing in the third century B.C.,

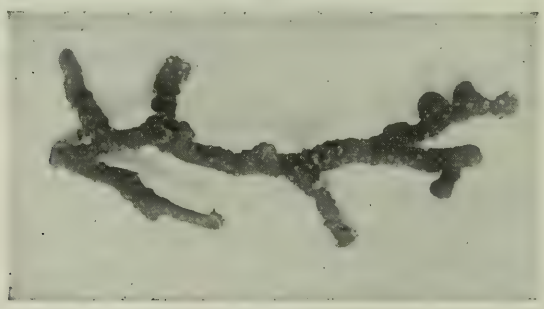

FIG. 139.—PHOTOGRAPH OF PRECIOUS CORAL—CORALLIUM RUBRUM.

(Photo by Author.)

describes this coral. In accordance with the Doctrine of Signatures the old Romans thought that the blood red color of this indicated that it was a specific blood medicine to

be used for cooling the blood and to reduce inflammations. Little branches were supposed to ward off the terrible consequence of the "evil eye." Such pieces are still carried with this hope by some people in Italy. A French dealer in precious stones in the seventeenth century stated that large perfect specimens were purchased by the Japanese who paid as high as $20,000 for them.

Physalia (Fig. 140), the Portuguese Man-of-war, is a compound Hydrozoan sometimes picked up along the Atlantic coast. It has the appearance of a beautiful iridescent bladder or float about six inches long. The prevailing color is blue, although other prismatic colors appear. Underneath the float are feeding, tactile, egg-producing and sperm-producing individuals. Still others have long tentacles which when relaxed trail down several feet in the water. When small fish come in contact with these, the batteries of nematocysts paralyze them, and, tentacles coiling about the fish raise it up to the feeding polyps which consume it at leisure. Physalia is an object of great beauty. It is also of great interest because of the organization into a colony of so many types of individuals. There is

(Amer. Mus. Nat. Hist.)

FIG. 140.—PHOTOGRAPH OF MODEL OF PHYSALIA, PORTUGUESE MAN-OF-WAR.

some degree of unity of organization, but not such unity as is shown by the higher animals which are organizations of different systems of organs. In these higher types the organization is more unified. Physalia is somewhat like a group of specialized organisms, none of which could function well alone. In the higher animals there is but one organism and the special physiological functions are detailed to special parts of that organism.

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CHAPTER XII

PHYLUM IV. PLATYHELMINTHES

Phylum IV includes flatworms, liver-flukes and tapeworms. The body is *dorsoventrally* compressed, the symmetry is *bilateral*, that is, the right half of the body is a duplicate of the left half. There is a definite upper or *dorsal*, and *ventral* or under body surface and also a definite head or anterior end and a posterior or hinder end. These relations are connected with the usual forward linear movements of the body, not with irregular turning movements of animals with mere axial or radial symmetry, such as Protozoa or jelly fishes. Mesoderm has appeared in addition to ectoderm and endoderm. In this mesoderm, well-developed organs of excretion and reproduction have been organized. A distinct nervous system is present and this shows the beginning of a brain. There is no respiratory or circulatory system. The alimentary canal, if present, has a mouth but no special anus. Most forms are *hermaphrodite*. There are three classes of Platyhelminthes: *I. Turbellaria; II. Tremotoda; III. Cestoda.* Descriptions of representatives of each class give a more definite idea of the characteristics of this phylum.

Class I. Turbellaria.—*Example Planaria.* (Fig. 141.) This is a little, fresh-water flatworm. It is about a centimeter in length. The front end is blunt and the hinder end pointed. Inside the body is the intestine composed of endoderm. The mouth opens into the *pharynx* located on the ventral side behind the middle. This pharynx may be protruded like a proboscis. The pharynx leads into the intestine which has three main trunks from each of which lateral sacs or tubes originate. Some portion of the intestine is

near almost every part of the body. Food is digested in all of its branches and is absorbed through the endoderm cells in the neighborhood. It is transferred to the mesoderm and its organs near by and to the ectodermal structures near by also. There is thus no need for a circulatory system. The intestine provides absorbable food in the neighborhood of all the outer organs. In the mesoderm is a well-defined excretory system. This consists of two long urinary ducts which open to the outside on the dorsal surface toward the rear of the animal. To each of these ducts is connected a series of side branches. All these tubes are composed of a layer of flat cells. Each branch ends internally in a flame cell which has irregular branches extending out into the rest of the mesoderm. The flame cell possesses a hollow cavity which connects with the end of a urinary tube. At the blind outer end of the cell cavity is a mass of cilia and, in the body of the cell, vacuoles appear. These resemble the contractile vacuoles of the protozoa. Evidently wastes are absorbed from the fluids in the mesodermal spaces. These wastes collect as vacuoles in the body of the flame cells and are then discharged into the hollow cavity of these cells. The vibrating cilia drive the waste fluids into the excretory channels and so to the outside. Probably the contractions of the worm's body assist in the expulsion. Just underneath the ectoderm is a layer of circular muscle cells, and under this layer occur layers of longitudinal and oblique muscles. Contraction of these muscle tissues accomplish the movements of the worm. Each worm possesses two sets of sex organs. (Fig. 142.) The ovaries are located in the mesoderm in the front portion of the body. Two long oviducts extend from the ovaries to the *genital cloaca* or chamber. Yolk glands connected with the oviducts secrete yolk

FIG. 141.—PLANARIA MACULATA, SHOWING PHARYNX, INTESTINE AND EYE SPOTS.
(After W. C. Curtis.)

about the eggs as the latter pass from the ovaries to the genital chamber. There are a number of *testes* from which the sperm pass into branching ducts which connect with a pair of long sperm ducts or *vasa deferentia*, which also open by means of a proboscis-like organ, the *penis*, into the genital chamber. Copulation takes place. Sperm from one worm are introduced into the genital chamber of a second worm whose eggs are thereby fertilized. There are two long nerve cords in the lateral regions of the body. Lateral branches from these two strands serve to form a network of nerves. A special concentration of nerves occurs at the head end. This indicates the beginning of the formation of a brain. Two masses of pigment toward the dorsal surface at the head end and connected by nerves with the brain are especially sensitive to light and form a rudimentary eye.

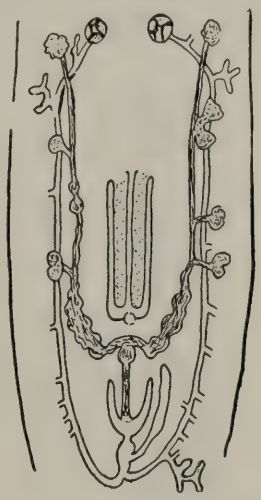

FIG. 142.—PLANARIA SIMPLISSIMA.

Male and female reproductive organs. At upper end in middle is one pair of ovaries. Connected with these are oviducts, along which are located yolk glands. On the left are shown three testes and on the right, four testes. Sperm pass from the testes into a vas deferens on each side. Vas deferentia join canal in penis below the pharynx. (After W. C. Curtis.)

Class II.—Trematoda (Fig. 143) are parasitic in many animals. *Distomum hepaticum*, the liver fluke, is parasitic in the liver of the sheep or other domestic animals, causing "rotten liver" and the death of the host. It has a complicated life history. The animal is flat, leaf-like in form, an inch in length by a half inch in width. A single liver may harbor 200 parasites. Each fluke may produce thousands of eggs. These are discharged with the feces. They develop outside the host into free swimming larvae known as *Miracidia*. If the miracidia land in a pool of water they swim about actively. If there are snails of the genus Lymnoea or Helix present in the water, the fluke larvae bore into the tissue of the snails. Within the snail's body the larvae reproduce

asexually into a number of other larvae known as *rediae*. Each of these primary rediae may form asexually more rediae. The rediae give rise asexually to 15 to 20 *cercariae*. These leave the snail, swim about in the water for a short time, and then may become attached to grass stems and encyst. If eaten by a sheep the young fluke is freed of its cyst wall in the intestine of the sheep and makes its way through the bile duct into the liver. In six weeks it is sexually mature and produces miracidia again. About 3,000,000 sheep were killed in 1879–80 in an epidemic of sheep rot in Great Britain.

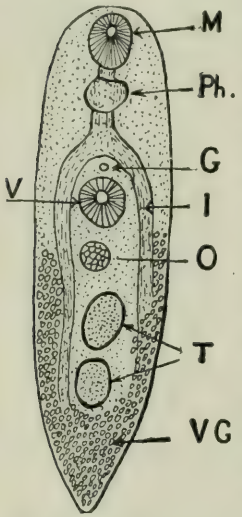

FIG. 143.—DIAGRAM OF DISTOMUM GLOBIPORUM, A TREMATODE FOUND IN INTESTINE OF WINTER FLOUNDER.

M., Mouth; *Ph.*, Pharynx; *G.*, Genital pore; *V.*, Ventral sucker; *O.*, Ovary; *T.*, Testes; *V. G.*, Vitelline glands. (Linton, U. S. Bur. Fisheries.)

Class III.—Cestoda. Tape Worms (Fig. 144).—There are many species of Cestoda or tape worms inhabiting the intestines of many animals. *Taenia solium* is a type which sometimes inhabits the human intestine. The body of the worm is tape-like in appearance, consisting of many segments or *proglottids*. It is bilaterally symmetrical and has a permanent head end or scolex with hooks and suckers. New flat proglottids are constantly being formed behind the head and old "ripe" proglottids are constantly being cut off from the hinder end. There is no vascular, respiratory, or digestive system present. Oxygen and digested food are absorbed through the proglottid walls from the contents of the intestine. There are well-defined nervous and excretory systems. However, what is more important is the fact that each proglottid is supplied with ovaries and testes and each can produce a great many fertilized eggs. After fertilization inside the proglottid, the latter is swollen with developing embryos. These proglottids are detached and pass out of the intestine

with the feces. The embryos are set free. In this stage they may possibly be eaten by a pig or a cow. In this intermediate host the embryos, which possess six hooks at the anterior end, bore their way through the intestines into the muscles and encyst there. The hooks disappear, the embryo increases in size and from one side there develops a bud which grows into the cavity of the "bladder like" form of the embryo. On account of this form these asexual passive stages are called bladder worms. The ingrowing bud develops into a head or *proscolex* and a neck. Later this proscolex and neck are everted. If a man eats this infected meat the bladder worm is released from the "bladder" and the head with its crown of hooks and four suckers, becomes attached to the wall of the intestine and then the tape worm continues to grow as long as the head or scolex remains attached to the wall of the intestine.

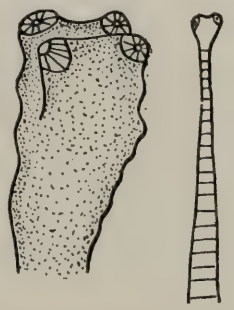

FIG. 144.—TAPE WORMS.

At left, scolex of Taenia from eel; at right, scolex and proglottids of Taenia from shark. (Linton, U. S. Bur. Fisheries.)

Tape worms are very common in the intestines of dogs and cats. Parasitism has resulted in the degeneration of the intestinal tract of this flatworm, and has also deprived the animal of the possibility of an independent existence.

In all the parasites above noted a wealth of reproductive material is manufactured, because the chances against the continuance of the species are very great. An enormous number of embryos must be produced in an attempt to insure the growth to maturity of a single one. In Africa there is a *trematode* which infests the blood vessels of the urinary bladder of man. A certain tape worm has larvae which sometimes infect man and produce large swollen sacs causing the disease known as *Hydatides*, which may cause death. Another tape worm has a larva which lives in the brain of some domestic animals causing the disease known as "staggers." Man escapes largely from these infections because as a rule he eats thoroughly cooked meat.

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CHAPTER XIII

PHYLUM V. NEMATHELMINTHES

Nemathelminthes are long slender worms and are called *round* or *thread* worms. Many of them are parasitic. They are unsegmented. The alimentary canal is a tube extending the length of the body ending in a posterior opening, the anus. A nervous, excretory and reproductive system are present. The sexes are usually separate. There is no circulatory or respiratory system. The life history is often very complicated. *Ascaris* (Fig. 145) is a genus having a number of species inhabiting the intestines of many animals. *Ascaris megalocephala* lives in the intestine of the horse and is a long cylindrical worm pointed at each end, about six to ten inches in length.

Other species of Ascaris are found at times in the human intestine, especially in children, where little harm is done. The parasites probably enter with vegetable food. *Trichinella* causes the disease known as *Trichinosis*. The parasite enters the body when poorly cooked meat infested with parasites is eaten. Each parasite may produce in the intestine of the pig 10,000 young. These burrow through the intestinal wall into the muscles where they encyst (Fig. 146.) Eating such meat after imperfect cooking may result in infection of the human body. As many as 15,000 of these parasites have been found in one gram of human muscle. They may lame the muscles of jaws, neck, and chest so much that death may result from the loss of vital functions. *Filaria* (*bancrofti*) is a round worm which sometimes lives in blood vessels of tropical man. It is one of the causes of the disease known as *Elephantiasis*, in which the limbs are swollen to an enormous size. The worms migrate to the blood vessels of the skin at night. From this region

they may be taken up by certain mosquitoes and thus transferred to other persons. Another species of this genus

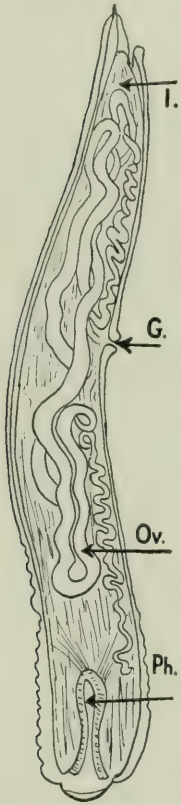

FIG. 145.—ASCARIS, A NEMATODE FROM THE SUMMER FLOUNDER.

Ph., Pharynx; *Ov.*, Ovary; *G.*, Genital pore; *I.*, Intestine. (Linton, U. S. Bur. of Fisheries.)

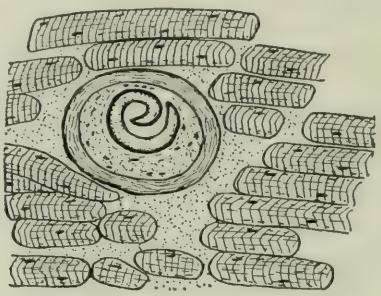

FIG. 146.—TRICHINELLA.

Cyst showing part of worm in striated muscle.

FIG. 147.—DIAGRAM OF NECATOR, AMERICAN HOOK WORM.

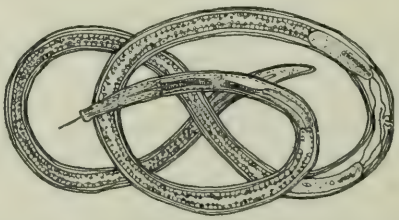

FIG. 148.—XIPHINEMA, THE DAGGER NEMATODE.

Injurious to plants, being able to thrust spear at head end, through tough covering of roots into inner living tissues. (From Cobb, U. S. D. A.)

lives under the skin of man in Africa and other tropical countries. It is usually found in the legs and feet where it produces serious ulcers. Some people believe that such

worms were the " burning fiery serpents " which plagued the Children of Israel.

Necator americana (Fig. 147) is the American hookworm which infects the small intestine of man. It moves about in the intestine sucking blood and thus not only debilitating the victim, but rendering him liable to infection by serious bacterial diseases. It is prevalent in the southeastern United States where it is claimed that about 2,000,000 persons are rendered economically unfit by it. Infection is brought about by drinking infected water, eating infected foods, or even by the parasites boring through the soles of the bare feet from infected soil.

Hair worms, *Gordiacea*, are sometimes found in freshwater ponds and resemble horse hairs. Since they are sometimes found in watering troughs it has been a common belief that the long horse hairs which fell into the water changed into worms, but of course this is not the fact.

Other *Nematodes* live a free life in fresh or salt water or in decaying vegetable matter in the soil (Fig. 148). Most of them are parasitic in plants or animals. They are being actively investigated by the U. S. Public Health Service and by the Department of Agriculture, in the Bureau of Plant Industry. N. A. Cobb, in charge of the investigations, estimates that one acre of alluvial soil contains three billion nematodes. He calls attention to the fact that " in countries where the wealth consists largely in live stock, as, for instance in the western part of this country, in Australia and in the Argentine Republic, the monetary loss caused by nematodes is always considerable, and sometimes very great." " A list of more or less serious human nematode diseases and ailments might be increased until practically half a hundred had been enumerated." " The common gallworm has been found infesting the roots of several hundred different species of plants, among them most of our cultivated crops, and causes an annual loss amounting to millions of dollars. There is another Nematode that has at times completely checked the growing of sugar beets in certain regions." " It may be estimated that more than 80,000 nematode species infest the forty-odd thousand spe-

cies of vertebrates." "Numerous as the parasitic species are, it is certain the number of species of nematodes living free in soil and in water far outnumber them." "There must be hundreds of thousands of species."[1]

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[1] *Nematodes and their Relationships* by N. A. Cobb.

CHAPTER XIV

PHYLUM VI. ANNELIDA

General Characteristics.—The Annelida constitute a separate phylum of worm-like forms. They are elongated and the body is segmented. Bilateral symmetry, anterior-posterior differentiation, and dorso-ventral differentiation are characteristic of them. There is an intestine with mouth and anus. Between the intestine and the body wall is the *coelom* or body cavity. In the development of the animal, the mesoderm forms two layers, one of which associates itself with the outer ectoderm of the body wall, while the inner layer of mesoderm associates itself with the endoderm and so with the intestine. The space left between the outer and inner mesoderm is the coelom or body cavity. In this cavity, internal organs, such as the kidneys, reproductive organs and blood vessels develop from the mesoderm. The appearance of a true body cavity is first noted in the *Annelids* and is retained by all higher animal phyla. The appearance of a true body cavity is considered of great importance in making possible a higher type of body organization.

Lumbricus—a Familiar Type. *External Features.* (Fig. 149.)—The common earthworm, Lumbricus, affords a familiar type for detailed study. It is purplish-brown in color and has about 160 segments. Between the thirty-first and thirty-seventh segments is a swollen part called the *clitellum.* On each segment are four pairs of short bristle-like *setae.* These are locomotor organs and are of great use when the worm is in its burrow. On the ventral side of most *somites* is a pair of openings of the *nephridia* or kidneys. In the grooves between the ninth and tenth and tenth and eleventh somites are two pairs of minute openings from the

internal seminal receptacle sacs. On the floor of the fourteenth somite are the two openings of the oviducts. On the floor of the fifteenth segment are the two openings of the *vasa deferentia*, ducts carrying sperm from the testes. The front segment of the worm is incomplete and forms a lip-like proboscis over the mouth. It is the *prostomium*. Perforated partitions extend from the body wall to the intestine. These are *septa* and appear as the ring-like lines separating one segment from another.

FIG. 149.—DIAGRAM, VENTRAL VIEW OF ANTERIOR END OF LUMBRICUS.

Sperm receptacles in neighborhood of 9th segment; Openings of oviducts and sperm ducts at 14th-15th segments; Clitellum begins near the 31st segment.

Digestive Tract (Figs. 150 and 151). —The mouth opens into the *pharynx* a spindle-shaped mass largely muscular and functioning in the swallowing of food. Behind the pharynx is the *esophagus*, a thin-walled tube concealed by adjacent organs. The esophagus extends from about the fifth to the thirteenth segment. Posterior to the esophagus is a large saccular thin-walled *crop*, extending from the thirteenth to the sixteenth segment. Posterior to the crop is a large saccular thick muscular walled *gizzard* extending from the sixteenth to the eighteenth segment. Posterior to the gizzard is the smaller tubular stomach-intestine which extends throughout the rest of the body to the anus. In the dorsal wall of the stomach-intestine is infolded a long ridge called the *typhlosole* which increases the internal surface of the intestine and contains cells which probably function in digestion and absorption. Small caliciferous glands at the side of the esophagus secrete into it an alkaline fluid which neutralizes acid food. The earthworm feeds at night, eating earth and small bits of plant and animal matter. Food passing into the crop is softened there, after which it is passed into

the gizzard where the muscular action of the gizzard walls grinds up the food between the grains of sand which are eaten with the food. Thence it passes to the stomach-intestine where different types of enzymes simplify it into compounds which can be absorbed. The absorbed food passes through the wall of the stomach-intestine into the coelom where it mixes with the coelomic fluid. It bathes many tissues and organs here and is probably absorbed directly by them. It may get into the blood vessels and be carried by them to various parts of the body.

Circulatory System.—The earthworm (annelid), is the first animal we have studied possessing blood and blood vessels (Figs. 150 and 151). There are a few axially located long

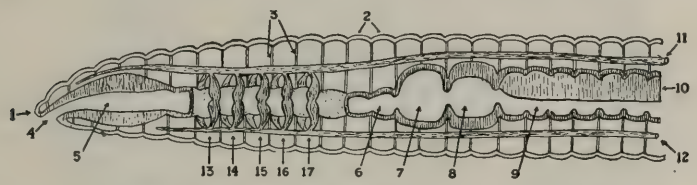

FIG. 150.—DIAGRAM OF SECTIONAL VIEW OF EARTHWORM.

1, Prostomium; 2, Somite; 3, Septa; 4, Mouth; 5, Pharynx; 6, Oesophagus; 7, Crop; 8, Gizzard; 9, Intestine; 10, Typhlosole; 11, Dorsal blood vessel; 12, the Ventral blood vessel; 13, 14, 15, 16, 17, the five hearts.

trunk blood vessels from which branches extend to the organs in their vicinity. There are five of these main trunks, first the *dorsal vessel,* which runs along the upper surface of the intestinal tract; second, the *ventral vessel,* which is underneath the intestine; and third, the *subneural vessel,* located underneath the nerve cord and two small *lateral neural vessels* along each side of the nerve cord. The lateral branches of these upper and lower main trunks connect with each other in various ways by means of smaller network-like capillaries so as to make a complete system. In the neighborhood of the esophagus on each side are five pairs of large trunks which connect the dorsal vessel with the ventral vessel. These are called the "hearts." Valves in the dorsal vessel and the hearts insure the flow of blood forward in the dorsal vessel. A great part of it is carried down by the

"hearts" to the ventral vessel. In general, the blood flows toward the rear in the ventral vessels back of the hearts, but forward in front of them. So that there is a continuous closed circulation in these vessels. The nervous system is especially well supplied with blood. The blood is propelled along the vessels by peristaltic waves which are made possible by the muscular structure of the larger blood trunks.

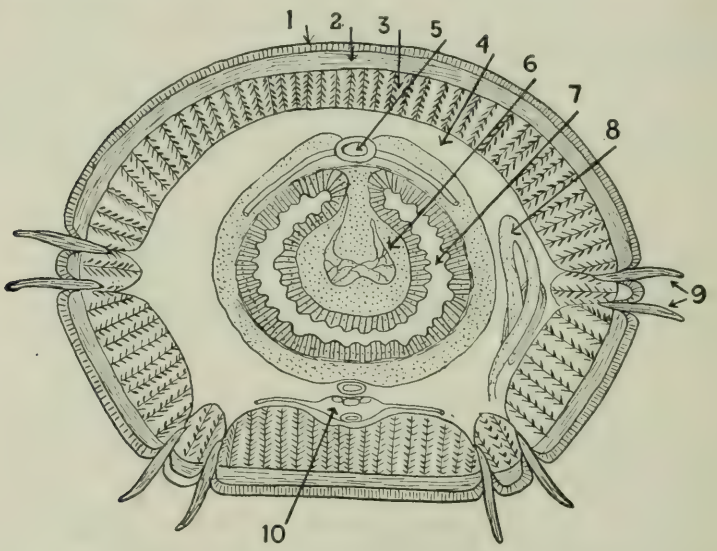

FIG. 151.—DIAGRAM OF CROSS-SECTION OF EARTHWORM.

1, Cuticle; 2, Circular muscles; 3, Longitudinal muscles; 4, Body cavity or coelome; 5, Dorsal blood vessel; 6, Typhlosole; 7, Intestinal cavity; 8, Nephridium; 9, Setae; 10, Ganglion. Just above it is ventral blood vessel and in its lower part is subneural blood vessel. (From section and after model by Ward.)

It consists of a liquid *plasma* in which minute colorless cells, *corpuscles*, are floating. The red color of the blood is due to the presence of a dissolved protein-iron compound called *hemoglobin*, which has the power of absorbing oxygen from the air and carrying it to all cells of the body.

Respiratory System.—There is no respiratory system. Capillaries are near enough to the surface so that the hemoglobin of the blood may absorb oxygen through the moist skin. The worm would die from oxygen starvation if

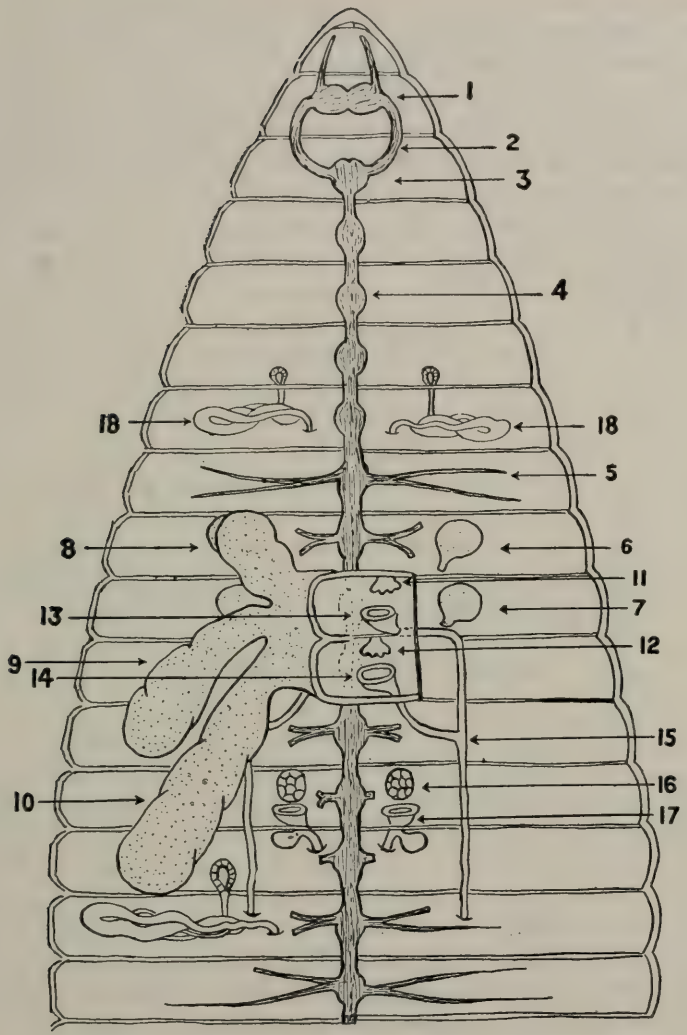

FIG. 152.—ANATOMY OF THE EARTHWORM. (DIAGRAMMATIC).

1, Suprapharyngeal ganglion or brain; 2, Nerve ring; 3, Sub-pharyngeal ganglion; 4, Nerve cord with ganglia; 5, Nerves; 6, 7, Seminal receptacles; 8, 9, 10, Seminal vesicles or reservoirs; 11, 12, Testes; 13, 14, Funnel-like openings of 15—the vasa deferentia or sperm ducts; 16, Ovary; 17, Oviduct with yolk gland; 18, Nephridium. This opens in body cavity in segment anterior to that in which most of it is located. (From model by C. H. Ward.)

the skin dried up. Carbon dioxide is discharged from the blood through the skin.

Excretory System.—In most of the somites is a pair of excretory organs or *nephridia*. A nephridium (Figs. 151 and 152) is a coiled tube which is located in the lateral lower portion between the intestine and the body wall. It opens to the outside on the floor of the somite. The internal portion of the nephridium passes through the *septa* in front and ends in a ciliated funnel called the *nephrostome*. Part of the coiled tube is lined with cilia also. The cilia create a current which draws fluid into the nephridium from the contents of the body cavity. Some part of this fluid is waste matter. Gland cells forming the body of the tubule probably abstract waste matter from the blood capillaries which closely invest the tubule.

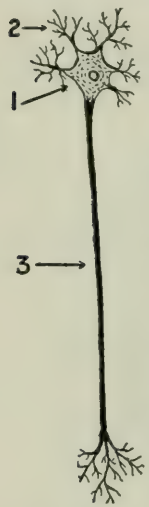

FIG. 153. DIAGRAM OF A NEURON OR NERVE CELL.

1, Cell body; 2, Dendrites; 3, Axone.

Nervous System.—In the earthworm there is a centralization of nerve cells (Figs. 151 and 152). Underneath the intestine is a long white cord, the ventral nerve cord. In each segment the cord presents a swelling, the *ganglion*. Under the pharynx, the nerve cord ends with the *subpharyngeal ganglion*. From the sides of this, lateral cords extend up on either face of the front of the pharynx ending above in the *bilobed suprapharyngeal ganglion* or brain. Each of the ganglia of the nerve cord is bilobed also. From each ganglion nerves extend out into the organs and tissues adjacent to them. A nerve cell (Fig. 153) consists of three parts; first, a larger, cell-like part which contains cytoplasm and the nucleus; second, a series of short branching roots, which connect the cell body of one nerve cell with another, and third, the *axone* or thread-like process which serves mainly to conduct the impulses. The nerve-cell body is a sort of relay station or battery. The nerve-cell axones are the " wires " along which the nerve " current " runs. The ganglia noted above are aggregations of nerve cell bodies

and their connecting or synaptic branches. The nerve cord is a linear arrangement of ganglia and connecting nerve strands. The nerves which extend to the tissues from the ganglia are bundles of axones. The brain of higher forms is a larger aggregation of nerve cell bodies. There are two types of nerve cells. First, those that conduct impulses from the surface to the ganglia of the nerve cord. Such nerve cells are called sensory or *afferent cells* because they

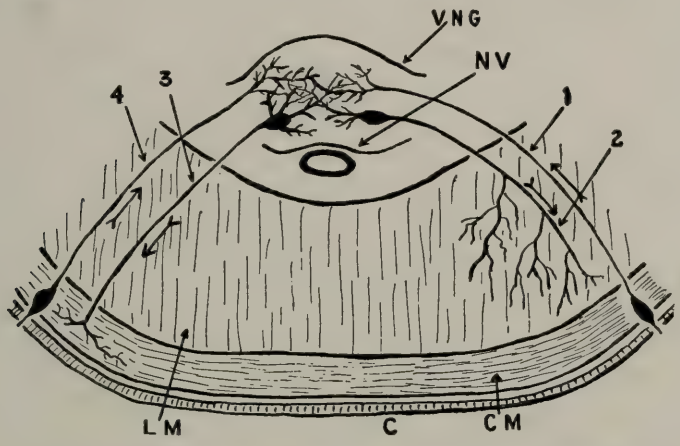

FIG. 154.—DIAGRAM OF A REFLEX MECHANISM IN LUMBRICUS.

C., Cuticle; *C. M.*, Circular muscles; *L. M.*, Longitudinal muscles; *V. N. G.*, Ventral ganglion; *N. V.*, Subneural blood vessel; 1 and 4, Sensory neurons; 2 and 3, Motor neurons. Sensory neurons are receptors and motor neurons are adjustors. The latter end in muscles, effectors. An impulse coming in over 1 may flow out over 2 or over to 3. Also an impulse coming in over 4 may return over 3 or pass over to 2. The impulse may extend in the nerve cord forward and backward.

convey impulses, aroused by external stimuli, toward the central system. Second, other nerve cells conduct impulses from the ganglion out to a muscle, causing it to contract. They are motor nerves. By nerve impulse is meant some sort of physico-chemical change which progresses along the nerve fiber.

A ganglion and the sensory and motor nerves to and from it constitutes a simple reflex apparatus (Fig. 154). An external stimulus affects a sensory nerve cell in the skin of the worm. Since this cell receives the stimulus it is called a

receptor. The receptor sends an impulse into the ganglion. Here it is transferred to a motor cell. This cell is called an *adjustor* because it adjusts or may modify the incoming impulse. The muscle aroused to action by the efferent impulse of the adjustor cell is therefore called an *effector*. The movements and activities of the earthworm are simple reflexes or combinations of them. If the stimulus is small and very definitely localized it may arouse a nervous reaction (reflex) restricted to a few segments in the neighborhood of the stimulus. However, if the stimulus is great enough all the segments may be involved in the resulting reaction. Let us suppose that a powerful beam of light is suddenly turned on to the head end of a worm in a dim place. The sensory nerves to the brain are strongly stimulated and motor impulses pass not only to muscles supplied by brain adjustors, but the subpharyngeal and all the posterior ganglia are aroused to action and motor impulses flow out to muscles all along the line because the ventral nerve cord between the segmental ganglia consists of axones which connect the various ganglia. The earthworm is sensitive to various forms of external stimuli. Certain epidermal cells are sensory. However, there are no specialized sense organs. The pigment spots characteristic of the lower form, *Planaria*, are absent.

Reproductive System (Fig. 152).—A pair of ovaries is located in the floor of the thirteenth segment. Behind them are the funnel-like openings of the short oviducts which open to the outside of the body on the floor of the fourteenth somite. In the ninth, tenth, eleventh and twelfth segments are large sac-like organs with central reservoirs in the tenth and eleventh segments and sac-like projections of these running forward into the ninth segment; laterally into the eleventh and also back into the twelfth segment. These sacs are known as the *seminal vesicles*. They serve to store sperm and sperm fluid. The *spermatozoa* are made by the testes. There are two pair of testes, small organs, one pair in the tenth and one pair in the eleventh segment; one pair of sperm funnels in the tenth segment and one pair in the eleventh segment just posterior to the testes connect

with branch tubes which connect, in turn, with the long tubular *vasa deferentia*. The vasa deferentia convey the spermatozoa from the seminal vesicles to the outside of the worm at the fifteenth somite. Each worm is thus hermaphroditic (*monoecious*). Two worms come together with the ventral surface of the front portions of the bodies in contact so that segments nine to eleven of one are opposite the fifteenth segment of the other. Slime tubes are formed at the clitellum. The worms discharge spermatic fluid from the vasa deferentia. This fluid, with the sperm in it, is conveyed into the seminal receptacles of the other worm. After the worms have separated the slime tube is worked toward the head end. As it passes the fourteenth segment eggs and yolk are discharged into it. As it passes the eleventh to ninth segments its body contractions pass sperm from the seminal receptacles into the slime tube. It should be remembered that although these sperm are added to the eggs by the same worm that lays the eggs, yet the sperm were actually made by another worm. The slime tube containing eggs and sperm is passed off the anterior end of the worm. Then the open ends of the slime tube close up and a saclike cocoon is formed in which the fertilized eggs develop and from which small immature earthworms emerge some time later.

Embryology.—The fertilized egg divides, passing through a blastula stage and, later, a gastrula stage. This elongates somewhat and a mouth is formed by an ingrowing tube at the blind end of the gastrula. The solid mesoderm which has formed between the ectoderm and endoderm develops spaces in it. These spaces are the embryonic beginnings of the body cavity. As the worm grows the body cavity increases also. The mesoderm partitions between the coelomic segments become the septa later.

Behavior.—The earthworm exhibits very definite responses to stimuli of various sorts, such as bright light, chemical and mechanical stimuli. The body attempts to draw away from irritating objects. Some stimuli, such as food, may produce a positive reaction. Experiments indicate that the earthworm is not altogether a simple

machine. For under certain circumstances it exhibits an ability to learn by experience for a short time. As an experiment, an earthworm was set free on the top of a box filled with earth. Avoiding the light it crawled here and there, finding one or the other of two burrows, one of which contained a pair of electrodes. If it started down the electrified burrow it received a slight shock which caused it to withdraw. It crawled around and tried the burrows again and again. After a certain number of trials it " learned " to crawl immediately into the " safe " burrow when released. In other words, it had the nervous organization which enabled it to profit by experience. It possessed memory to a certain extent.

Regeneration.—The earthworm possesses great powers of regeneration. A piece removed from the front end of the body will regenerate a new tail at the hinder end and in time a completely organized worm. Similarly, a piece removed from the tail end will regenerate a new head at the front end. Sometimes another tail grows out from the front end. This form does not live very long. A piece may be removed from the middle of one worm and grafted in between the front and tail end of another worm. As a result a worm longer than any found in nature will result.

Economic Importance.—Charles Darwin studied carefully the effects of earthworms on soil. His book on the " Formation of Vegetable Mold through the Action of Worms " was written after studies made for forty years. He estimated that a certain acre of ground contained a population of 50,000 worms. In forming burrows the earthworm passes the earth from the mouth through the anus to the outside near the entrance of the burrow. In this way the earthworm slowly and in small amounts turns over the soil. Darwin estimated that eighteen tons of subsoil per acre are spread out to sun and air (and thus sterilized) every year by earthworms. Moreover, the formation of burrows carries air into the soil and moisture is retained more easily. In thirty years' time a stony field was entirely covered with new turf and most of this was accomplished by the action of earthworms.

Classification.—The Annelida are divided into three classes:

1. *Archiannelida* without setae or other segmental appendages. This is a small group of small, marine forms possessing characteristics which indicate that they are ancestral forms.

2. *Chaetopoda.*—This group comprises most of the annelids. They are fresh water or marine or land forms. Most of them are segmented; they also have appendages on the segments. This class is divided into two subclasses:

a. The Polychaeta. Nereis (Fig. 155) is called the sand or clam worm and used as bait by sea fishermen. It lives

Fig. 155.—Diagram of Nereis, a Polychaet Annelid.

in burrows in sand or mud along the seashore. Nereis possesses lateral flat appendages called parapodia (alongside feet). It is somewhat more highly differentiated than Lumbricus in that there are two pairs of eyes and tentacles and biting jaws at the head end. The parapodia serve as propelling organs and as gills. The palolo worm of the Samoan and Fiji Islands comes to the surface in swarms to breed at the full moon in October and is caught by natives for food. Many polychaetae reproduce asexually by serial or lateral budding. In some there are two regions of the body, an anterior sexless and posterior sex region. The posterior sex region separates from the anterior region in which event the anterior region produces another posterior sex region again. Some marine worms make tubes of sand which are carried about with the occupant of the tube.

b. The Oligochaeta.—These are mostly fresh water or terrestrial forms which are hermaphroditic. They have neither parapodia, tentacles, nor well-defined sense organs, although the front end of the body is more sensitive to external stimuli. There are over twice as many Polychaets as Oligochaets. Lumbricus is an oligochaet.

3. *Hirudinea.*—The leeches (Fig. 156). These are aquatic animals found in fresh water. Some are predaceous, eating other annelids, snails, etc. Some of them are external parasites sucking blood of aquatic vertebrates. The body is segmented internally. A large sucker at the posterior end and a small one at the anterior end are used in locomotion. In the blood-sucking leeches the animal liberates a secretion which prevents the coagulation of the blood. Extracts of the desiccated bodies of this leech contain such non-coagulable material. This is known in medicine as *hirudin* and is employed in certain conditions where the non-coagulation of the blood is an essential part of medical treatment.

FIG. 156.—HIRUDO, THE LEECH.

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CHAPTER XV

PHYLUM VII. THE ECHINODERMATA

General Characteristics.—The *Echinodermata* are marine animals with an apparent radial symmetry. They have a five-rayed body and, as a rule, a calcareous exoskeleton in which are spines or plates. There is present also a special water-vascular system consisting of tubes containing fluid and a special apparatus called tube feet concerned in locomotion. In the larva the symmetry is bilateral and there is active locomotion. However, a complicated metamorphosis occurs, as a result of which the adults secondarily acquire a radial symmetry which was originally present in the gastrula stage of the embryo and a slow kind of locomotion.

FIG. 157.—ASTERIAS—COMMON STARFISH (ASTEROIDEA).

Morphology and Physiology.—The starfish, *Asterias* (Fig. 157) is a very common animal along the seashore. The body is flattened and has five radial arms of equal size. The mouth is in the center of the lower surface and in the middle of the upper surface is the anus. Somewhat to one side of this is a convex small perforated plate called the *madreporite*. A plane passing through the anus, mouth and madreporite divides the animal into a right and

left side, thus revealing the line of bilateral symmetry. The surface of the body is covered with small calcareous nodules just beneath the thin ectoderm. These nodules constitute the skeleton. Along the center of the ventral surface of each ray is the deep *ambulacral groove*. Projecting from this is a double row of ambulacral feet or tube feet called *locomotor organs*. The tube feet emerge from two rows of perforations in the skeleton. At the tip of each arm is an eye spot. The mouth opens into a large *cardiac sac* or first part of the stomach which has a lobe toward each arm. This chamber leads by a constricted tube into the *pyloric stomach* which is pentagonal in shape. From the outer end of each portion, a smaller canal extends and immediately divides into two long pyloric glands running out toward the tip of each arm. The pyloric glands are attached to the upper surface by means of sheets of tissue (mesenteries). The rest of the intestine is short, but attached to it is a pair of anal glands. The *cardiac stomach* is attached to the lower surface by muscles. This part of the stomach can be protruded out of the mouth and extended in between the two halves of an oyster shell and in this way the starfish consumes the tissues of the oyster. The water vascular system (Fig. 158) is part of the body cavity. It consists of a ring canal around the mouth and five radial canals extending into the arms. Each radial canal gives off paired lateral canals which lead to small sac-like enlargements, the *ampullae*, and from each of these a tube foot extends through the pores to the outside of the starfish. Between two of the radial canals a single short stone canal extends up to the madreporite. The walls of the water-vascular system are muscular. When the walls contract, water is forced out into the tube feet, making them rigid and capable of acting as feet. The tip ends of the tube feet

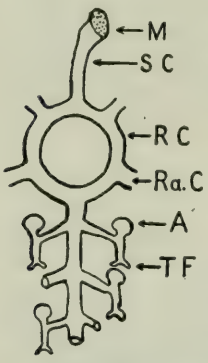

FIG. 158. — WATER VASCULAR SYSTEM OF A STARFISH.

M., Madreporite; *S. C.*, Stone canal; *R. C.*, Ring canal; *RaC.*, Radial canal; *A*, Ampulla; *T. F.*, Tube foot.

form suckers. When the foot is pushed against an object and then retracted the end of the foot sticks to the object because of the vacuum formed by the sucker and the muscular contraction pulls the animal along. The sea-water in the ambulacral system is replenished through the stone canal from the madreporite. The ambulacral system is probably respiratory as well as tactile and excretory. The fluid in the ambulacral system is kept in circulation by cilia inside the tubes. A well-developed nervous system is present, and conforms to the radial symmetry. The sexes are separate, although males and females resemble each other externally. There are five pairs of gonads which open separately to the outside, where the eggs are fertilized.

FIG. 159.—PENTACRINUS, A SEA LILY (CRINOIDEA).

Embryology.—A well-defined blastula (Fig. 128) and gastrula stage (Fig. 129) is present. The gastrula develops into a free swimming larva. From the bilateral symmetry of this larva the radial symmetry is later developed.

Regeneration.—The starfish has great powers of regeneration. If an arm is lost, it is replaced by a new one. In fact, at times, a new starfish will regenerate from a single arm. This power of regeneration is shared by all the Echinoderms. Oyster farmers cannot rid the beds of starfishes by cutting

them in two and throwing the pieces back into the sea.

Classification.—The phylum is divided into five classes and is made up of about 4000 species, so far as is known at present.

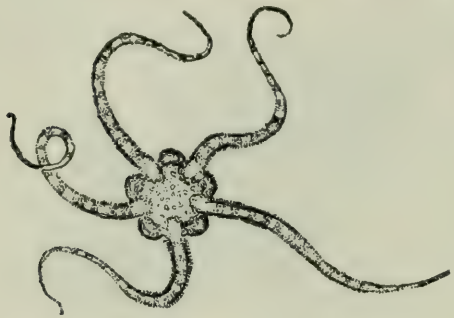

Fig. 160—Ophiopholis (Ophiuroidea).

Class I. Crinoidea (Fig. 159) are feather stars which are attached (for part of the life period, at least) by a stalk to the sea bottom. The mouth surface and mouth opening are directed upward. Some of them are deep sea forms.

Class II. Asteroidea (Fig. 157) are the starfishes so-called because the arms are prolonged like a five-rayed star. The oral surface is toward the substratum and the anus is above. The body axis is vertical and short. Starfishes are probably the most commonly observed Echinoderms. They move about slowly by means of their tube feet, and constitute a real danger to the oyster industry because they always appear in numbers on oyster beds where they wrap their arms over the oyster, kill it and feed on it. They also eat crustaceans. Starfishes were well known to Aristotle, (384-322 B.C.).

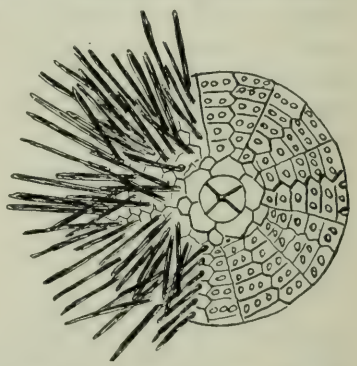

Fig. 161.—Arbacia—sea urchin (echinoidea).

Class III. Ophiuroidea (Fig. 160).—Brittle stars. These animals resemble the Asteroidea but the five rays are slender and elongated projections from a central disk. The animal progresses by the snake-like movements of its arms. They are the most

numerous of the Echinoderms in number of species and they feed on small animals or seaweeds.

Class IV. The Echinoidea (Fig. 161) have no arms. The body is globular, as in the sea-urchins, or disk like, as in the sand dollar. Projecting from the mouth are five calcareous teeth. Sea-urchins are covered with spines, the basal end of each of these being attached to the body surface by a ball and socket joint. In some sea-urchins the body is covered with a thick investment of slender spines, while in others there are but a few thick and longer spines. In some, the tips of the spines are posionous. Sea-urchins are widely distributed in salt waters near the shore. The gonads are used as food by some maritime people and it is stated that over a hundred thousand dozen are sold in Marseilles each year. Aristotle named these animals. He understood to a certain extent the internal anatomy and called attention to the resemblance of the dental apparatus to a lantern and it is known to this day as "Aristotle's Lantern."

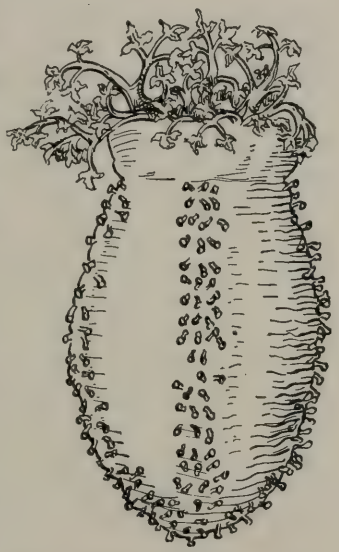

Fig. 162.—Pentacta—sea cucumber (holothuroidea).

Class V. Holothuroidea. (Fig. 162).—Sea-cucumbers are Echinoderms in which the body wall is soft. There are no spines or tube feet. The body axis may be elongated, giving to the animal a worm-like appearance. The animal rests upon its side with the mouth and anal ends raised somewhat above the main body mass. The mouth end is provided with branching tentacles. The radial symmetry is still present. The internal organs are homologous with those of other echinoderms. The body wall is very muscular. Under certain conditions a sea cucumber will evert its internal organs. In the sea water a peculiar substance on the sur-

face of some of these organs swells up into a mass of threads. Enemies are tangled up in this and made helpless. Although the animal may lose its internal organs, it possesses the power to regenerate new ones. In the Far East Holothurians are dried and used for food. This is the " trepang " of the Chinese. Aristotle originated the name Holothurian.

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CHAPTER XVI

PHYLUM VIII. MOLLUSCA

General Characteristics.—The *Mollusca* are bilaterally symmetrical animals in which the body is enclosed in a calcareous shell. Ectoderm, mesoderm and endoderm are present and also a body cavity. From the ventral side of the head extends the *muscular foot*, the organ of locomotion, while from the dorsal side originates the *mantle*. This is an extensive skin fold which also covers the visceral mass. The outer surface of the mantle secretes the shell. The body is not segmented. Some Molluscs have no mantle and no shell. Some with a mantle have no shell. The respiratory system consists of a pair of comb-like gills located in the mantle cavity. The eyes are especially well developed in some groups. Most Molluscs are aquatic and mostly marine. Some have left the water for a terrestrial life although even these require moist conditions. There are over 60,000 species and very many fossil forms. The Mollusca comprise the largest animal phylum outside the *Arthropoda*. Common examples are clams, snails, oysters, scallops, squid and octopus.

Morphology and Physiology.—Unio (Fig. 163) is a freshwater mussel and lives in the bed of lakes and streams. Carbonate of lime must be present in the waters inhabited by the mussel. It can move from place to place or burrow with its foot. This it can project forward between the open anterior end of the shell. From the opened shell at the posterior end also extend two tubes called the incurrent and excurrent *siphons* (Fig. 164). Water with oxygen and food is drawn into the ventral siphon and wastes of metabolism are passed out of the dorsal siphon. The shell consists of two parts, the valves fastened together

dorsally by an elastic hinge or ligament. The concentric lines on the surface of the valves indicate growth increments. The hump near the anterior dorsal region marks the early life of the young clam. The shell is made up of three regions. An outer, thin, horny layer is protective in nature, a middle layer is of crystals of calcium carbonate and an inner lining is the nacreous layer composed of a number of thin layers formed by the entire surface of the mantle producing a prismatic effect with light and is therefore called mother-of-pearl. The valves are held together by two transverse muscles. These are located near the dorsal surface at each end and are called the *anterior adductor* and the *posterior adductor*. As the animal grows they shift their position further and further apart. Inside the shell are the mantle folds attached to the inner surface of the valves along a line near the edge. Within the mantle folds are the gills, the foot, and the viscera. (Figs. 165 and 169a.)

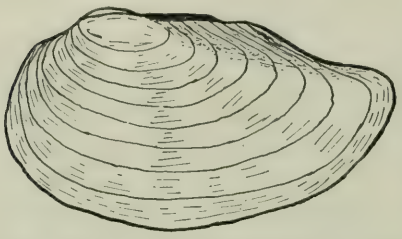

FIG. 163.—UNIO, A FRESH-WATER CLAM.

The mouth is located between two pairs of *labial palps* behind the inner part of the *inhalent (ventral) siphon*. Cilia on the inner sides of these palps drive the food into the short oesophagus or gullet which opens into the *saccular stomach* on either side of which is the *glandular liver*, the secretions of which pass into the stomach by minute ducts. Food and organic matter are drawn into the mantle cavity with the water through the *incurrent siphon*. Posterior to the stomach is the intestine, which is a tube of smaller caliber than the stomach. It coils about the basal part of the

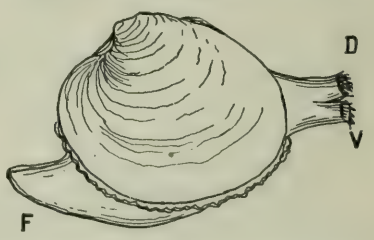

FIG. 164.—VENUS MERCENARIA, HARD SHELL CLAM, MARINE.

D., Dorsal siphon; *V.*, Ventral siphon; *F.*, foot.

foot and then runs toward the dorsal surface and passes through the *pericardium* and ends in an *anal papilla* in the chamber behind the *excurrent siphon.* Most of the digested food is absorbed through the wall of the intestine. The pericardium is a chamber under the hinge and between the two muscle masses. In it lies the tubular and muscular heart. The ventricular part of the heart

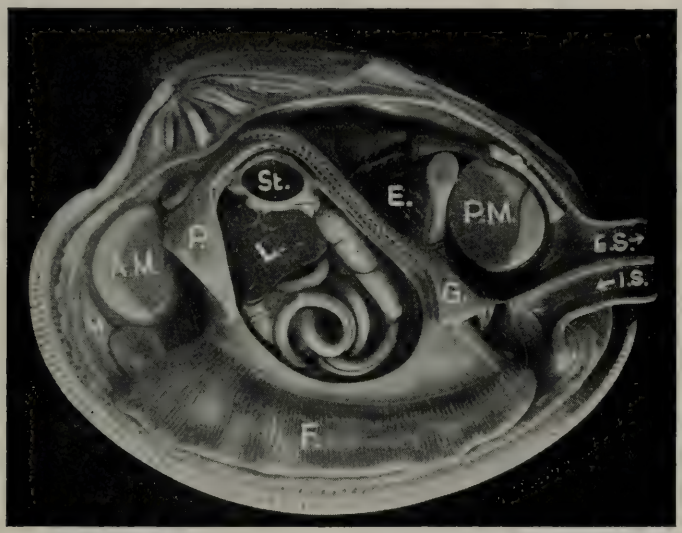

FIG. 165.—ANATOMY OF HARD SHELL CLAM, VENUS.*

E. S., Excurrent siphon; *I. S.*, Incurrent siphon; *R.*, Rectum; *P. M.*, Posterior adductor muscle; *G.*, Gilis; *E.*, Excretory organ; *St.* Stomach; *L.*, Liver; *I.*, Intestine; *F.*, Foot; *A. M.*, Anterior adductor muscle; *M.* Mantle; *P.*, Palp. (Photograph of model in Amer. Mus. Nat. Hist.)

surrounds part of the intestine. The *anterior aorta* extends from the ventricle forwards and the *posterior aorta* extends backwards. Contraction of the ventricle sends the blood forward and backward through these vessels. In its circulation the blood passes through the kidneys and gills and back through auricles and into the ventricle again. Dissolved food and oxygen are carried by the blood to all tissues of the body and carbon dioxide is released from the blood as the blood passes through the gills. Nitrogenous

wastes are removed from the blood as it passes through the kidneys. The gills are vertical pairs of plates which hang down beneath the mantle on either side of the foot and visceral mass. Within each *gill lamella* are vertical water tubes separated from each other by interlamellar partitions. Each lamella consists of a number of *gill filaments*. Blood vessels are also found in the gill filaments. Openings or *ostia* provided with cilia run from the outer surface of the lamella to the water tubes. Water drawn into the mantle cavity through the incurrent siphon passes through the ostia into the water tubes, thence into a chamber above the gill plates and thence into the dorsal mantle cavity and out through the dorsal siphon. Blood absorbs oxygen from the water circulating over the gill surface and discharges carbon dioxide into the water from the blood.

There are two kidneys just under the pericardium. Each kidney has two parts, a ventral glandular part into which the pericardium opens by a slit, and a dorsal thin bladder which opens to the outside by a renal papilla. Possibly some wastes are driven into the glandular kidney by the cilia at the pericardial aperture. Other wastes are removed from the blood by capillaries in the glandular kidneys. All are discharged through the dorsal siphon.

The nervous system is somewhat concentrated. On each side of the oesophagus is the cerebral *ganglion*. The two are connected by a ring which passes above the oesophagus. From each of these ganglia a nerve runs ventrally ending in the pedal ganglia in the foot. Each cerebral ganglion also sends a nerve cord backward through the kidneys to a *visceral ganglion* beneath the posterior adductor. The edges of the mantle have sensory cells which are also present on the ventral siphon and are sensitive to contact and light. The *statocyst* is a small vesicle just behind the *pedal ganglion*. It contains a small amount of calcium carbonate and is probably an organ of equilibrium.

Mussels are usually dioecious, that is, the sexes are separate. The reproductive glands are located in the foot. The spermatozoa are carried out through the dorsal siphon of the male and are drawn into the ventral

siphon of the female. The eggs pass out of the genital aperture and are caught by the gills at many places. Here they are fertilized by the sperm. The fertilized eggs undergo cleavage and pass through a blastula and gastrula stage and then develop into a larva known as the *glochidium.* (Fig. 166.) This is very small and has a two-valved shell, the free edges of which are toothed in some forms. Fertilization occurs in the late summer. The larvae remain in the gills through the winter. In the following spring they are discharged through the dorsal siphon. When they come in contact with a fish they become attached to it by closing the valves and the skin of the fish grows around the clam embryo which thus obtains nourishment. The *glochidia* of some forms lodge in the gill filaments of fishes and develop there. After some weeks spent as a parasite the young mussels are liberated and take up an independent existence. The clam lacks great powers of movement. The interposition of this parasitic glochidium stage insures distribution by the fish.

FIG. 166.—GLOCHIDIUM OF LAMPSILIS, A FRESH-WATER MUSSEL

(After Lefevre and Curtis, U. S. Bur. Fisheries).

Classification.—There are a number of classes of *Mollusca.* Among these are the Gastropoda, the Pelecypoda and Cephalapoda.

FIG. 167. — NATICA, A MARINE GASTROPOD.

1. *The Gastropoda* number about 49,000 known species. They are commonly called snails, which name is applied to the aquatic marine forms as well as to the land forms. The body is asymmetrical with a spirally coiled shell (Fig. 167.) This spiral twisting causes a rearrangement of the internal organs with the loss of the left member of paired organs in most snails in which the spiral turns to the right hand. The head bears tentacles and eyes. There is a foot on the ventral side of the body. Most snails are *oviparous,* laying their eggs in various kinds of egg cases. Also most of them are aquatic. *Helix pomatia* is the French

snail of the New York markets. In Africa, shells of the *Cyprea* (cowrie) are used as money.

2. *The Pelecypoda* (*Lamellibranchiata*) number about 11,000 species living to-day. These are symmetrical bivalved

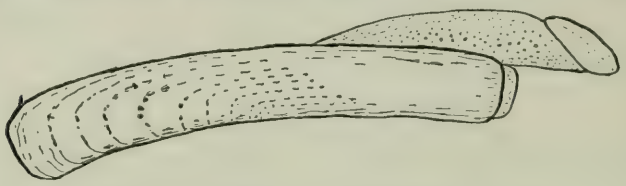

FIG. 168.—ENSIS, THE RAZOR-SHELL CLAM.

molluscs without any head. The anatomy of the Pelecypoda is indicated by the description of Unio. They are all aquatic and mostly marine, many being found in shallow waters. In the Pacific Ocean is found a giant clam, *Tridacna gigas*, over three feet long and weighing 250 pounds. On the other hand

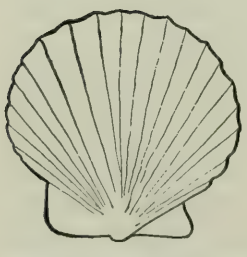

FIG. 169.—PECTEN, THE COMMON SCALLOP.

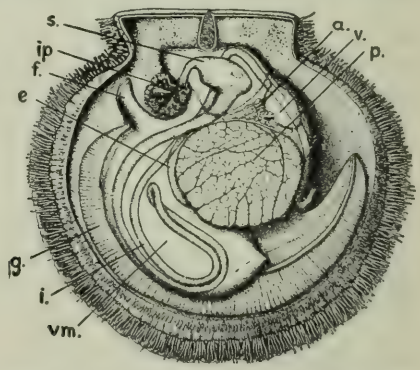

FIG. 169A.—ANATOMY OF GIANT PECTEN.

F., Foot; *i. p.*, Labial palps; *S.*, Stomach; *I.*, Intestine; *G.*, Gill; *V.*, Ventricle; *P.*, Posterior adductor muscle. (There is no anterior adductor muscle.) (From Drew, Biol. Bulletin.)

the small, fresh-water *Pisidium* is but a few millimeters in length. The razor shell clam, *Ensis* (Fig. 168), can dig its way into the sand with surprising rapidity with its spade-like foot and then, by twisting the foot sidewise, resists removal. *Pecten* (Fig. 169), the scallop, swims rapidly by

clapping the shells together and goes skipping along in and out near the surface of shore waters. Some Pelecypoda can bore channels into clay or rocks and thus are protected from their enemies. *Mytilus*, the salt-water mussel, attaches itself to sticks or rocks by the thread-like mass called the *byssus* and resists removal by predatory fish. (Fig. 170.)

Pelecypoda are of great economic importance. The oyster fishery is one of the world's great industries. Taking of oysters (Fig. 171), from natural beds and placing them in waters where they would be more protected and more available was practiced in Italy long before the founding of the Roman Empire. It is said that oysters were shipped to Rome from England in those early days. There are oyster fisheries today in Europe, Asia, Africa, Australia and the Americas. In the United States most of the oysters are obtained along the seashore from Massachusetts to Texas. Oyster farming is most successfully practiced in an artificial way in France. The world's supply of oysters totals an annual income of over $20,000,000. Over 100,000 people are engaged in this industry. It cannot be said that the oyster is of high food value although it does contain some protein and considerable glycogen or animal starch. It is supposed to be easily digested, but is desired chiefly because of its peculiar appetizing flavor.

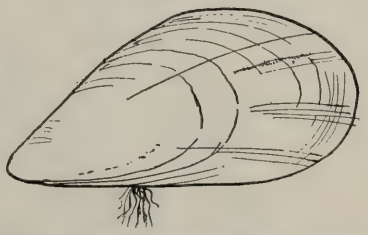

FIG. 170.—MYTILUS EDULIS, EDIBLE MUSSEL.

The sexes are separate in the Atlantic coast oyster. The female develops annually about 60,000,000 eggs which are microscopic in size. Many times as many sperm are probably produced by the males. Discharged into the water in the spring when the water temperatures are rising, the sperm swim about until they come in contact with an egg and fertilization takes place. In a few hours a swimming embryo is developed. The shell gradually forms.

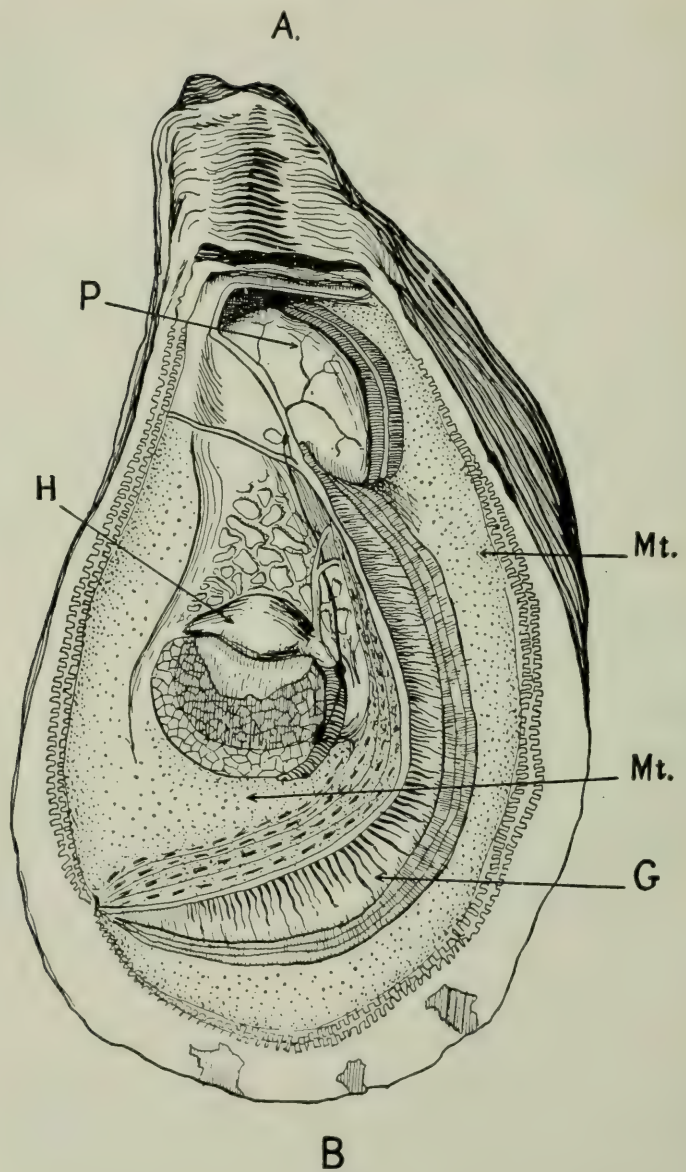

FIG. 171.—OSTREA, THE OYSTER.

Anatomy, left valve shown. *A.*, Ant. end; *B.*, Post. end; *P.*, Labial palps; *Mt.* Mantle; *G.*, Gill; *H.*, Heart. (From U. S. Bur. Fisheries.)

When the animal is fully surrounded by the valves the yolk is all used up. At this time, from one to two days after fertilization, the animal becomes a larva in which condition it swims about after food. The left valve now gradually grows more rapidly than the right. In about two weeks, still very small, it attaches itself to an old shell or rock. This is the " set " or " spat " stage. In about four or five years it has become of marketable size. Oyster fishermen in " farming " oysters provide a bed of clean old shells on which the " setting " can take place. Spawning occurs after the first year. Oysters feed on the minute organisms or *plankton* of the seawater. If the waters in which they are grown contain sewage, there is danger of contamination with forms of human intestinal diseases such as typhoid

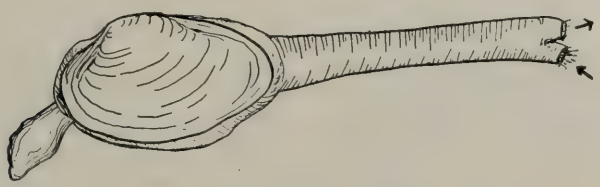

FIG. 172.—MYA ARENARIA—SOFT-SHELLED CLAM.

fever. In general, at the present day, ordinances enforced by boards of health protect the consumer from these dangers. Chemical wastes from industrial developments have destroyed oyster beds. Other enemies of the oyster are animals which consume the free swimming embryos. The oyster drill (gastropod), *Urosalpinx* drills through the shell into the interior for its food.

About 1,000,000 pounds of clams (Figs. 164 and 172) are marketed in the United States at an annual value of about $2,000,000. The culture of clams by artificial methods is in its early stages in New England. The value of the scallop industry is about $750,000 annually. The *Abalone* of California, found mostly along the southern coast, is also of considerable economic importance, although the supply is decreasing. The salt-water mussel, *Mytilus edulis* (Fig. 170), constitutes a source of food which has not as yet been fully

recognized by the harvester of seafood. About two centuries ago buttons were first made from mollusc shells in Austria. In 1914, over 20,000,000 gross of pearl buttons from fresh-water clam shells were made in the United States and over 4,000,000 gross of marine shell mother-of-pearl buttons, both kinds having a value of about $7,500,000. The world's production of pearl objects amounts to millions annually. Very few shells suitable for this purpose are obtainable in the United States, but about $2,000,000 worth are imported here each year.

Sometimes a boring sponge or worm will burrow through the outer layers of an oyster shell. Possibly grains of sand get in between the mantle and inner layer of shell.

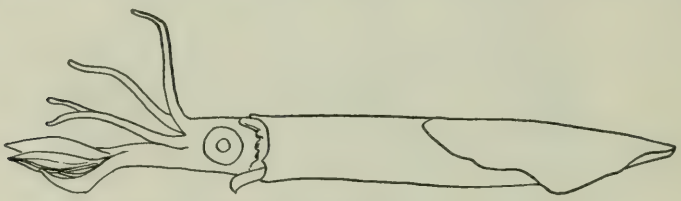

FIG. 173.—LOLIGO, THE SQUID, A CEPHALOPOD

(After Drew.)

The mollusc will then deposit mother-of-pearl at this point to allay the irritation. A little mound collects and forms a blister pearl which resembles the segment of a large pearl. These do not possess the same concentric disposition of *nacreous* layers as in real pearls, but they are utilized in the manufacture of jewelry. "The pearl," says Dr. G. F. Kunz, "is the most precious, costly, richest, and most beautiful of all objects of human adornment." It is not a precious stone, but is of organic origin. Some irritating substance or object such as the larva of a round worm comes to rest in the connective tissue of the mantle and assumes a spherical form. It soon dies and the tissues form a structureless mass which the pearl oyster covers with successive layers of nacre until a pearl is formed. It may not be an organism which acts as the stimulating or irritating agent, but granules of one sort of another. The mother-of-pearl

is deposited in layers one over the other. The surface appears crumpled and corrugated and the edges have tooth-like outlines. This arrangement causes rays of light to be reflected from the surface much as light is reflected from a soap bubble, so that an iridescent effect is produced. Pearls have been found in Egyptian tombs dating from 3000 B.C. The twin pearls of Cleopatra have been estimated to have been worth about $56,000 apiece. At the World's Fair in Chicago, in 1893, there was exhibited a string of 52 pearls valued at over $1,000,000. Probably the most important pearl fishery is located in the Persian Gulf. Bahrein Island is the headquarters of the pearl fishermen. About 35,000 men are engaged in the work and there is a fleet of about 3500 vessels. Pearls have been obtained from this locality for over 2000 years.

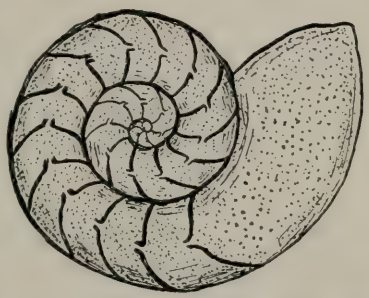

FIG. 174.—SECTION OF SHELL OF NAUTILUS.

3. *Cephalopoda.*—These are Molluses having a head provided with tentacles instead of a foot. The tentacles are supplied with suckers. Cephalopods also have well-developed eyes. Examples of Cephalopods are squid, nautilus, and octopus. The squid (Fig. 173) is an active swimmer. It can capture a fish with its tentacles, hold it with the suckers, and tear out pieces of flesh with its beak-like jaws. It has an ink sac and when the ink is discharged a black cloud of water hides the squid from its enemies. Squid is used as bait by salt-water fishermen. Dried squid is considered good food by Orientals. The devil fish or octopus may attain considerable size and is a dangerous enemy. The *Nautilus* (Fig. 174), has a shell with spirally arranged compartments formed one after the other to accommodate the growing animal

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CHAPTER XVII

PHYLUM IX. ARTHROPODA

Introduction.—*Arthropoda* are closely related to Annelids. They possess bilateral symmetry; the body is segmented and some or all of the segments bear appendages. A distinctive feature is the segmented character of the appendages. Three classes of *Arthropods* are noted here. *I. Crustacea* which are aquatic and breathe by means of gills and have two pairs of antennae; *II. The Insecta,* air-breathing Arthropods having one pair of antennae; and *III. The Arachnida,* air-breathing Arthropods which have no antennae.

Class I. Crustacea.—A general idea of the structure is obtained by a study of the crayfish or lobster. (Fig. 175.) The animal lives in the water. Its food is both plant and animal. In fact, crayfishes often feed on crayfishes. It swims backward rapidly by strong strokes of its tail or creeps forward on its rather weak legs. In its growth it sheds its shell or moults several times. It is rather helpless and not at all secure from attack just after moulting. The body shows two main regions—(*a*) *cephalothorax* which is a combination of head and thorax, and (*b*) *abdomen.* A horny or chitinous exoskeleton supports and covers the soft inner tissues. The head-thorax includes segments one to fourteen. A groove separates the head from the thoracic region. The *carapace* is the hard dorsal cover of the cephalothorax and it is extended in front into the pointed *rostrum.* A side shield protects the gills. Each segment bears a pair of jointed appendages. There is considerable variation in these, but similarities in all are evident. The most anterior pair are the *antennules,* which are sensitive to touch, to chemical stimuli and serve as equilibrating organs.

The second pair are the long antennae which are organs of touch and chemical sense also. The third pair are the heavy strong jaws or *mandibles* used for crushing food; the fourth and fifth pairs are the first and second *maxillae*, the latter of which create water currents in the gill chamber: the sixth, seventh and eighth are *maxillipeds*, which are organs of tactile and chemical sense and help hold food particles; the ninth pair are very large and are the *chelipeds* or pincers used in fighting, in walking and tearing food; the tenth, eleventh, twelfth and thirteenth together with the chelipeds comprise the walking legs and

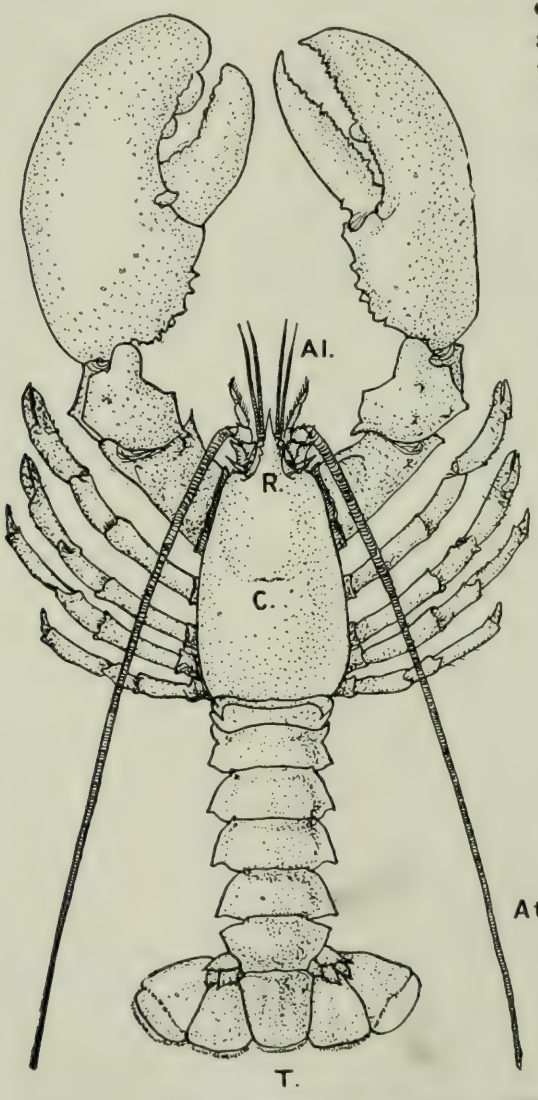

FIG. 175.—HOMARUS AMERICANUS, AMERICAN LOBSTER.

Al., Antennule; *R.*, Rostrum; *C.*, Carapace; *At*, Antenna; *T.*, Telson. (From U. S. Bureau of Fisheries.)

behind these the fourteenth, fifteenth, sixteenth, seventeenth, eighteenth and nineteenth abdominal segments are the abdominal appendages somewhat reduced in size. The nineteenth has flat, broad plates used in short jerky movements in swimming. The body cavity or *coelom* is small. The muscles and nerve cord also show signs of segmentation.

Crayfish feed at night and are most active at twilight and toward sunrise. The maxillipeds and maxillae hold the food while it is being crushed by the mandibles. The food passes from the mouth (Fig. 176) into the oesophagus then into the front chamber of the stomach (*cardiac part*), where it is ground up between horny plates (gastric mill), then it passes in fine pieces to the pyloric stomach where it is mixed with enzymes conveyed by hepatic ducts from the digestive glands. It is then sent to the intestine where it is digested and absorbed. Undigested particles pass to the posterior end of the intestine as fecal matter to be discharged through the anus. The crayfish also regurgitates large indigestible pieces.

Circulatory System.—The blood is colorless and contains ameba-like cells. It carries food and oxygen to tissues and wastes and carbon dioxide from tissue. There is a heart on the dorsal side just under the carapace of the thorax. A number of arteries extend from the heart. The blood passes out from the arteries to sinuses or spaces in the tissues. By its contraction the heart pumps the blood out through the arteries to all parts of the body. Valves in the arteries near the heart prevent the blood from returning to the heart. There is a large ventral blood space called the sternal sinus where blood collects and passes to the gills. From the gills the blood passes to the *branchio-cardiac sinus* which extends from the gills to the *pericardial sinus* surrounding the heart. The blood passes or is sucked into the heart through openings or ostia from the pericardial sinus when the heart relaxes and expands after a contraction.

Respiratory System.—A number of gills lie in a space on either side of the thorax covered by flaps of the shield on the side of the *thorax*. A current of water is kept up from

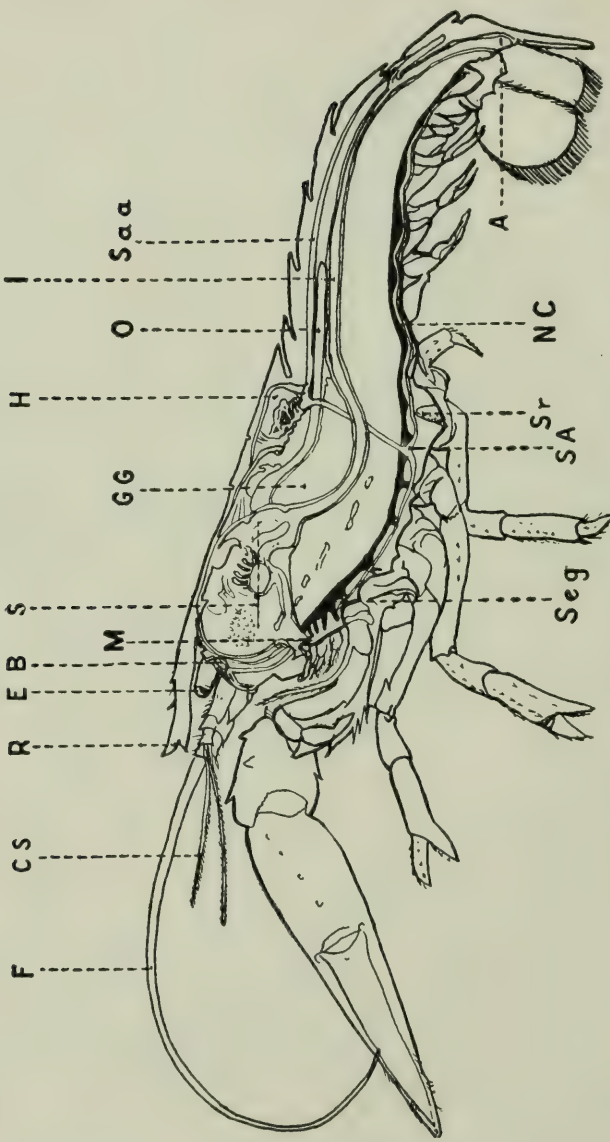

FIG. 176.—ANATOMY OF HOMARUS.

F., Antenna; *C. S.*, Antennule; *R.*, Rostrum; *E.*, Eye; *B.*, Brain; *M.*, Mouth; *S.*, Stomach; *Seg.*, Subesophageal ganglion; *S. A.*, Sternal artery; *H.*, Heart; *O.*, Ovary; *I.*, Intestine; *Saa.*, Superior abdominal artery; *A.*, Anus; *N. C.*, Nerve cord. (After Herrick, U. S. B. F.)

behind through the gill chamber and out in front by the paddling action of part of the second maxillae. The gills look somewhat like feathers. They consist of a framework covered with membranes richly supplied with capillaries and so arranged as to expose a large surface to the water.

The Excretory system consists of a green gland located behind the base of each antenna. It opens to the outside at a large knob on the basal joint of this organ. Each kidney consists of a dorsal green glandular part, a bladder-like portion and a duct which opens to the outside at the point named. Nitrogenous wastes are removed by the green gland from the blood.

The muscles are white in color. They are bundles of fibers and have cross-striations so characteristic of muscle tissue which contracts rapidly and is used for locomotion or any other rapid movement. They are inserted on the inner surface of the external shell. There are muscles which retract the tail, those that extend the tail, those that move the legs, those that bend the abdomen and straighten it and move the appendages.

Nervous System.—This resembles somewhat that of the earthworm. For example, the brain is a bilobed ganglion in the head in the dorsal region. From this ganglion nerves pass to the eyes, antennae and antennules. A connecting strand on either side of the oesophagus forms the *circum-oesophageal ring* which unites beneath and behind the oesophagus to form the *ventral nerve cord.* In segment seven there is a large ganglion called the *sub-oesophageal,* which represents the union of ganglia belonging to segments three to seven. Each segment behind number seven possesses a ganglion also. Nerves to all parts of the body pass from these ganglia.

Sense Organs.—The eyes are at the ends of movable stalks on either side of the head. These eyes are compound, that is, each eye is composed of a great many visual elements. The eye is covered with modified chitin called the *cornea.* The cornea is subdivided into areas known as *facets.* These are the ends of long visual elements called *ommatidia.* There are a great many on each eye. Each

tiny ommatidium is a complete visual apparatus. The side walls between these elements are lined with pigment through which light rays cannot pass but are absorbed. Only those rays which pass clear through the entire ommatidium will be visible. A mosaic picture of objects is formed. There are as many images as there are ommatidia. Each image is erect and not reversed as in our eyes. However, the images formed by the visual elements on the right side of the eye will not be the same as those to the extreme left. For example, those to the right will see more of the right field of vision while those to the left, more of the left field of vision. This type of eye records movement of external objects especially well. Any external change in position is registered on many little " eyes " of each eye.

Chitin-lined sacs called *statocysts* are located in the basal segment of each antennule. In them are many sensory hairs among which are a few grains of sand. Connected with the hairs are nerves. If the animal is crawling along horizontally, the sand grains will stimulate certain sensory hairs and a definite set of impulses will be sent to the brain. If the crayfish body is tilted to one side, other sensory hairs in the statocyst will be stimulated and another set of impulses will be sent to a slightly different region in the brain. This is one explanation of how the animal is made aware of the position of its body. We can call these *sense organs of Equilibrium.* The animal also senses the presence of food. This is the chemical sense and, as indicated above, is associated with certain of the appendages. Some appendages are also concerned with tactile sensations.

Reproductive Organs.—The sexes are separate. The male is more slender than the female. A bilobed testis is located beneath the heart. A pair of sperm ducts or *vasa efferentia* extend from the testis to the ventral side of the body and open to the outside at the genital aperture at the base of each fifth walking leg. The appendages of the first and second abdominal segments are modified to act as an organ for the transmission of the sperm from the male to the female. The eggs pass from the *ovarian sacs* into short oviducts which

open to the outside at the base of the third walking leg. Sperm are transferred to the *seminal receptacle* of the female during copulation. The seminal receptacle is a cavity in the fold of the exoskeleton between the fourth and fifth pairs of walking legs. Eggs are fertilized when they are laid. They are fastened by a sort of glue to the swimmerets of several abdominal segments and are oxygenated by being waved back and forth through the water. The eggs hatch in five to eight weeks. As the young crayfish grows it moults several times. This is called *ecdysis*. The outer layer of cells of the surface of the body secretes a new shell after the animal has moulted. The young animal moults several times during the first season. The young stay with the mother for a few weeks, then shift for themselves. Crayfish may live for four or five years.

Crustacea regenerate lost parts, but not to the extent possible in the Hydra or earthworm. Regeneration is more rapid also in young animals. In one case after an eye had been removed an antenna regenerated in its place. If the walking legs are injured, the crayfish throws off the entire leg at a certain joint called the "breaking point." This process is known as *autotomy* and is an actual definite process effected by the animal. Later a new appendage regenerates in place of the old one. The possession of the power of autotomy is of great defensive value. Crayfish show positive indications that they respond to such external stimuli as touch, chemical stimulus, and light, and they are able to learn somewhat by experience.

There are about 16,000 species of Crustacea. A few, such as land crabs and sowbugs (Fig. 177) live on land, but most forms are marine. They feed largely on decaying animal and plant matter. There are two subclasess; (*a*) *Entomostraca*, which are small forms without abdominal appendages; (*b*) *Malacostraca*, larger forms with abdominal appendages. Aristotle devised the name Malacostrata and he meant by it soft-shelled animals, to distinguish them from the hard-shelled Molluscs. The class includes lobsters,

crabs (Fig. 178), shrimps, beach fleas, sowbugs, barnacles which are sessile forms, and water fleas.

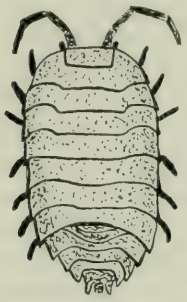

FIG. 177.—ONISCUS, THE SOW BUG. A land crustacean.

Parasitism occurs in many forms. The parasitic forms tend to lose their appendages, segmentation and sense organs, but the organs of reproduction are more highly developed. Some Crustacea live in partnership with other animals. The hermit crab lives in the cast-off shell of some sea snail and on the shell lives a colony of Hydroids (*Hydractinia*) or sea-anemones. Other crabs decorate the back of the body with seaweeds. This masking serves excellently as a defense. The Japanese spider crab is probably the largest of the Crustacea. Its small central body has attached to it long jointed legs. It may be twenty feet from tip to tip of the first pair of legs. Lobsters, shrimp and crabs are of great

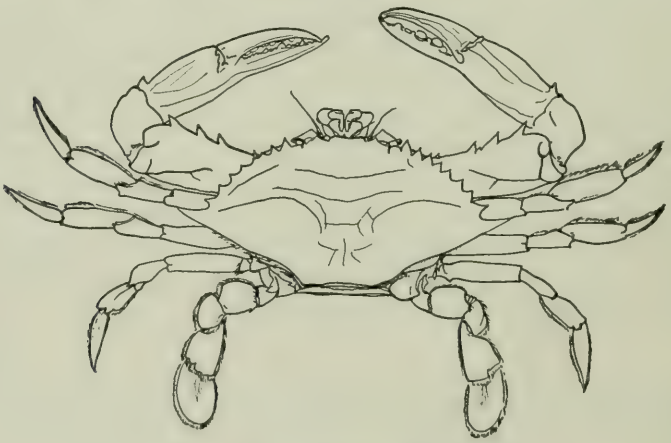

FIG. 178.—CALLINECTES—BLUE CRAB.
(U. S. Bur. Fisheries.)

economic importance. The most productive regions have been Canada, United States, Ireland and Norway. Maine has been the most productive state in the United States.

The industry was at its height here in 1892 when nearly 24,000,000 pounds of lobsters valued at over a million dollars were taken from the sea. On account of the decline in available numbers of lobsters this animal has been made the object of special biological investigations. The natural rate of propagation is not able to keep up the supply. This is probably due in part to the fact that not a sufficient number are left in the sea to reproduce and also that the young are taken before they reach the stage of actual sexual maturity. Many protective laws have been enacted to secure a larger increase

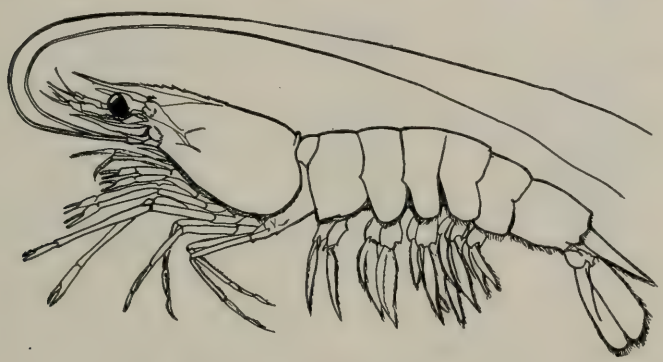

FIG. 179.—PENAEUS; SHRIMP.
(U. S. Bur. Fisheries.)

in yield in the United States and in some European countries. At present prices, lobster meat is a luxury. Lobsters spawn when about seven inches in length but attain sexual maturity when ten inches in length. The greatest recorded length is 23.75 inches and the greatest weight thirty-four pounds.

Three marine species of shrimp are taken for commercial purposes. They are migratory in habit and appear along the coast at regular seasons, usually in the spring and in the fall. The greater number of shrimp (Fig. 179) are taken by Mississippi and Louisiana fishermen in haul seines. Fishing is also done along the coast of Florida and Georgia where the catch is shipped to northern ports

in a fresh iced condition. Shrimp are canned and also dried.

Class II. Insecta.—These Arthropods have a segmented body, chitinous exoskeleton, ventral chain of ganglia joined by a nerve ring with a dorsal brain and jointed legs. The body is divided into three regions, head, thorax and abdomen. The head has a pair of antennae in front of the mouth and a number of pairs of mouth appendages. The thorax has three segments with a pair of legs on each. It usually has also one pair of wings on each of its hinder segments. There are no appendages on the abdomen.

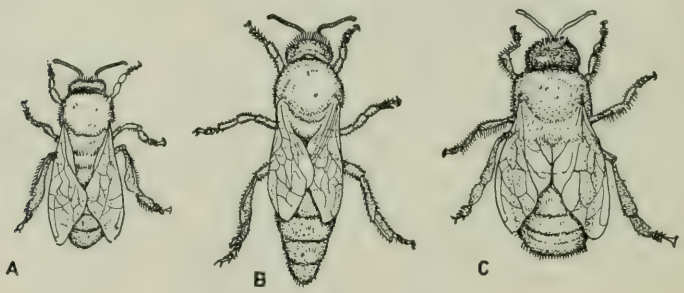

FIG. 180.—HONEY BEES.

A, Worker; *B*, Queen; *C*, Drone. (From Bur. Ento., U. S. D. A.)

The honey bee, *Apis mellifica*, is an example of one of the most useful and interesting of insects. The social life has attracted the attention of many students. Because it is economically beneficial it has long been domesticated by man. Three types of individuals live in a honey-bee colony (Fig. 180), (*a*) the males or drones are wholly reproductive—they do no other work about the colony; (*b*) the workers comprise the greater part of the population of many thousand. The reproductive organs of these workers (females) early degenerate. The young workers act as nurses to the young bee larvae and do not leave the hive. The older workers forage for food outside the hive. (*c*) The queen of the colony has unusually well-developed reproductive organs and to compensate for this does not possess so well-developed a brain and other organs as her infertile sisters.

The anatomical description which follows applies to the worker bee unless otherwise specified. The head consists of a number of segments (6) fused. On either side are two large compound eyes. These are larger in the drones. On the top of the head are three simple eyes. In front are two antennae and below are a number of mouth parts. (Fig. 181.) Just below the antennae is the *clypeus* and below this is the *labrum* or upper lip. Underneath this is the fleshy *epipharynx*, the organ of taste. On either side of the labrum is a pair of strong *mandibles*. The worker uses these in building the honeycomb. From beneath the labrum hangs down the *labium* or lower lip—in front of which is the *ligula* or tongue. It is long and flexible and has a spoon-like tip. The hairs along its edges are organs of touch and taste. It is also used in gathering nectar. On each side of the tongue is a *labial palp*. The *maxillae* are on either side. These are the lower jaws. They have palps also.

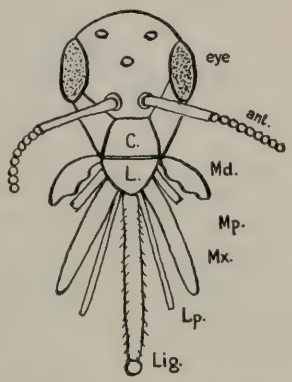

FIG. 181.—DIAGRAM OF MOUTH PARTS OF INSECT.

Eye, Compound eye; *ant.*, Antenna; *C.*, Clypeus; *L.*, Labrum; *Md.*, Mandible; *Mp.*, Maxillary palp; *Mx.*, Maxilla; *Lp.*, Labial palp; *Lig.*, Ligula. (From models in Amer. Mus. Nat. Hist.)

In gathering nectar the labial palps and maxillae form a tube in which the tongue moves back and forth. The nectar is collected on the hairs of the ligula and forced into the esophagus by the pressure of the maxillae and labial palps. There is a pair of legs on each of the three segments of the thorax (Fig. 182). Each leg consists of the *coxa* next to the thorax, then the *trochanter*, the *femur*, the *tibia*, and the five-parted *tarsus*. In the first pair of legs (*prothoracic*) the femur and tibia are covered with hairs for collecting pollen. The pollen brush is a segment covered with curved bristles at the outer end of the tibia. This brush is used to brush up pollen after the larger spines loosen it. On either side of this end of the tibia is a movable spine (*velum*). This fits over a space in

the *metatarsus*, which is the first part of the tarsus. It is lined with bristles and is called the *antenna cleaner*, as the antenna is drawn through

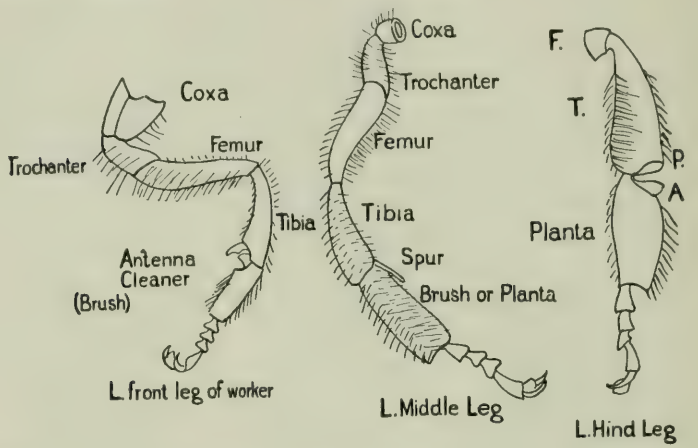

FIG. 182.—DIAGRAMS OF FORE-, MID- AND HIND-LEGS OF HONEY BEE.
(After Casteel, Bur. Ento., U. S. D. A.)

On the front of the metatarsus is a row of spines called the eye brush, used to brush out particles that might collect among the hairs of the compound eyes. The last joint of each leg has a pair of notched claws which makes it possible for the bee to get a firm hold on objects. Between the claws is the *pulvillus* which secretes a sticky substance, thereby making it possible for the bee to stand on smooth objects. The middle pair of legs have a pollen brush also, but instead of an antenna cleaner there is a spur used to dig out pollen collected on the pollen baskets on the third pair of legs.

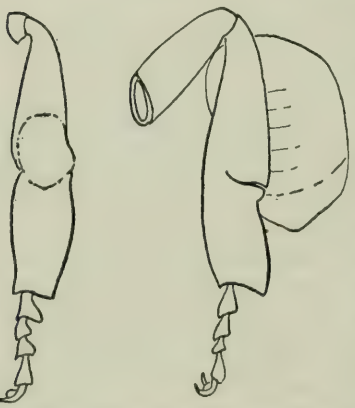

FIG. 183.—HIND LEG OF HONEY BEE.
At left a pollen basket partly filled; at right a load of pollen. (After Casteel, Bur. Ento. U. S. D. A.)

The *metathoracic legs* are larger. On the side of the tibia is a cavity flanked by rows of bristles. This is the pollen basket which the bee fills in its visits from flower to flower (Fig. 183). Along the metatarsus are hairs used to brush off pollen collected on the thorax and then placed in the pollen basket.

The wings are delicate membranes which act as rapidly moving planes.

The abdomen has six segments. At the posterior end of the abdomen of workers and queens is the *sting*. The drone has no sting but an organ of copulation instead. The stinging apparatus is quite complicated. A pair of feelers determine the best place for insertion of a pair of barbed darts which pierce the skin. A pair of coiled tubular poison glands in the body cavity secrete the poison and fill the poison sac. Compression of this discharges the poison along a groove between the barbed darts into the wound. After stinging, the whole poison apparatus is often broken off from the body and usually causes the death of the bee.

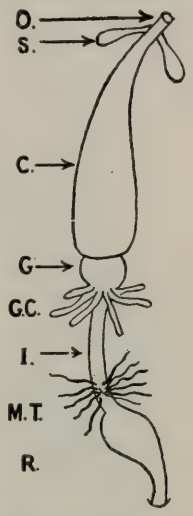

FIG. 184.—DIAGRAM OF INTESTINAL TRACT OF COCKROACH.

O., Oesophagus; *S.*, Salivary glands; *C.*, Crop; *G.*, Gizzard; *G. C.*, Gastric coeca; *I.*, Intestine; *M. T.*, Malpighian tubes; *R.*, Rectum.

The mouth connects with the long tubular oesophagus (Fig. 184). Three pairs of salivary glands discharge an alkaline secretion into the food passing through the oesophagus. Behind the oesophagus is the crop or honey sac. The bee can regurgitate food from this honey sac or pass it into the stomach behind it. Part of the digested food is absorbed through the stomach, but most of it is passed on to the intestine where the process is completed. Material not digested passes into the rectum or large intestine. From it undigested material is discharged through the hinder end of the intestine, through the anus. The blood is fluid plasma containing ameboid cells. The heart is a tubular organ above the intestine. Blood passes into it through openings in its side. From the heart the blood flows forward and

passes into spaces between the tissues and organs and so back into the heart again. On each side of the body are seven openings or *spiracles*. Five of these are in the abdomen. They lead into air tubes or tracheae which branch and form a complicated system of tubes throughout the body, carrying air directly to the tissues. For this reason the blood does not perform a respiratory function as air is delivered directly to the body cells. The excretory system consists of a series of long coiled tubes, the *malpighian* tubules, which discharge their secretions from body fluids into the intestine near the stomach.

Fig. 185.—Diagram of the central nervous system of cockroach.

A large bilobed brain somewhat similar to that of the earthworm is in the head above the oesophagus (Fig. 185). Nerves pass from this to such sensory structures as the eyes and antennae. A nerve ring around the oesophagus connects the brain with a large ganglion below as in the earthworm. Nerves from this ganglion supply the mouth parts. Behind this the ventral nerve cord under the intestine passes back to the hinder end of the abdomen. Ganglia are found along its course. In the thorax are two pairs, supplying wings and legs with nerves. Five ganglia are in the abdomen of the worker. Bees have organs of vision, the compound eyes, organs of smell, taste, and hearing on the mouth parts or mouth. In the drone are a pair of testes or sperm-producing glands. Sperm pass from these to the seminal vesicles where they are stored. These are connected with large mucous glands. From these they pass through the ejaculatory duct and by means of the organ of copulation, the penis, are passed into the seminal receptacles of the female during the act of mating with the queen. After mating, the drone dies or is killed by the workers who then likewise dispose of all the other drones. The workers have

undeveloped ovaries. In the abdomen of the queen is a pair of very large functional ovaries. Each consists of many egg-forming tubes. The mature eggs pass from the ovaries to the oviducts. These unite to form a common oviduct. The queen mates but once.

The workers, sterile females, rule the colony. They construct three principal types of cells (Fig. 186); 1st, Smaller worker cells in which workers will be raised; 2d, Somewhat larger drone cells; and 3d, large flask-shaped cells in which queens will be reared. In other cells honey is stored. The cells are roughly hexagonal in shape in cross-section. One group of cells is for breeding new members of the colony and many more than these are used for storing honey, to be used as food during periods when new honey cannot be made. The bee-keeper takes advantage of this habit and provides *comb* both for the reserve food supply for the colony and for an extra lot of honey which he takes from the hive. The queen lays an egg in each of the brood cells. She lays fertilized eggs in worker cells and queen cells or she can withhold sperm from eggs and deposit an unfertilized egg in a drone cell. She deposits them at the rate of two per minute for days and weeks.

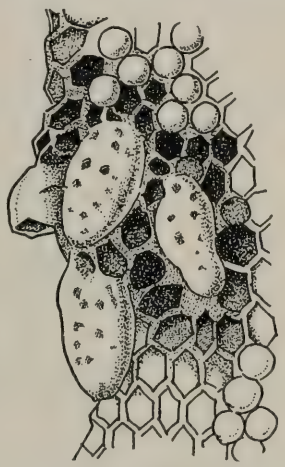

FIG. 186.— QUEEN CELLS OF HONEY BEE.

(After Phillips, Bur. Ento., U. S. D. A.)

The *wax glands* are in the abdomen. The worker removes the wax with the claws of the hind leg, carries it to the mouth (Fig. 187), mixes it with saliva, and places it just where needed in building new cells or capping cells. Bees collect a resinous gum from trees and with it cover the inside of the hive, make weak places strong and fill cracks.

The pollen, which the bees gather from flowers, is either eaten and digested by the bee or is deposited in the cells

as food for the growing young. Pollen is good protein food for the young. The bee is one of the principal agents in effecting cross-pollination of flowers. Bees also drink water and carry some of it back to the hive in the honey sac from which it is discharged into cells in which young bees are growing. The workers also get *nectar* from flowers. This is a dilute sugary solution which is swallowed and passed to the honey sac. The nectar is changed to honey in the honey sac or crop. When disgorged, it is placed in storage cells and these are not closed until it has lost part of its water. This dehydration is aided by air currents caused by bees buzzing in the hive. This also ensures a constant supply of fresh air in the hive. The workers keep the hive clean. They carry out dead bees or other insects that may have invaded the hive. The body wastes of the colony are removed. Some workers guard the entrance and prevent the admission of enemies.

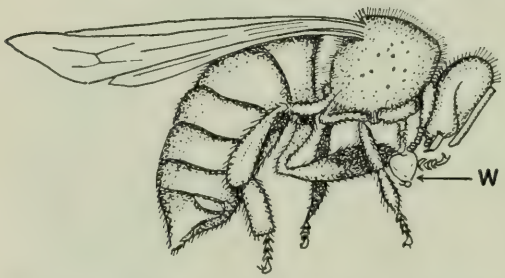

FIG. 187.—HONEY BEE TRANSFERRING WAX PLATE FROM ABDOMEN TO MOUTH.
(From Casteel, Bur. Ento., U. S. D. A.)

The eggs develop into larvae (Fig. 188) in the cells. Surrounding the larva is the food placed there by the workers. This is digested honey and pollen. The worker larvae are then fed more and more honey and digested pollen. The drone larvae are fed on honey and undigested pollen. The queen larvae are fed on "royal food" richer in nitrogenous material. When full-grown, the larval cells are capped. The larvae now form pupae. In time they leave the cells as full-fledged bees. The drones do not work, but have to find their own food. The newly formed workers at once assume duties, acting as nurses to larvae or attending to duties within the hive, but later venturing forth on food-gathering excursions. The colony gradually increases

in numbers. After a drone (male) mates with a queen, the drones are disposed of.

When new young queens emerge from the queen cells, the old queen becomes restless. She attempts a combat with the new queens and endeavors to kill them. All the workers stop work and a period of unrest ensues. If the colony is in a prosperous condition a *swarming* follows. Many of the workers prevent the old queen from attacking the new queen. Great numbers of them leave the hive surrounding the old queen and fly to some hollow tree or

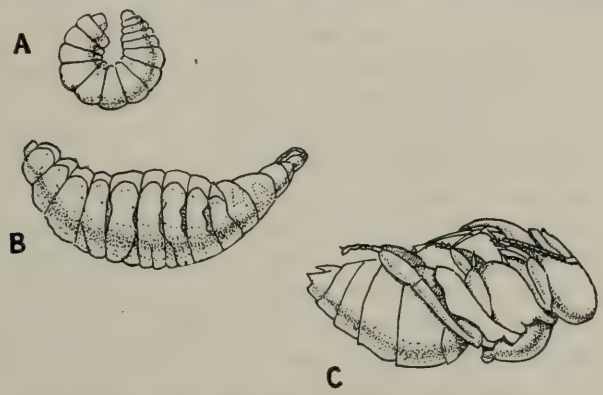

FIG. 188.—DEVELOPMENT OF HONEY BEE.

A. Young larva; *B*, Old larva; *C*, Pupa. (After Phillips, Bur. Ento., U. S. D. A.)

other similar place to start a new colony. The experienced bee-keeper makes a great noise by beating on tin pans and this induces the bees to alight on a branch near by. He very carefully cuts off this branch and carries the new colony to an empty hive which he has prepared for it. Thus a new colony is started. If more than one queen is left in the parent hive, the workers let the queens fight it out until but one queen is left. The young queen left in the old colony takes her " nuptial flight " with the drones. In this flight mating between the queen and a drone takes place. She is then able to lay fertilized eggs in the hive. If the ruling queen dies, the workers will make a large cell by tearing down the walls between three worker cells and feed some

worker larvae on royal food and so make queens of them. Swarming occurs in late spring or early summer.

There are more species of Insects known than all other animals taken together. Insects are responsible for millions of dollars of loss to agriculture every year. This is but a small item of the sum total of the disastrous effect that they have on human life the world over. They constitute man's greatest enemy. In fact, it is no exaggeration to state that the insect world is competing with man for dominance on this planet.

They are classified according to possession or non-possesson of wings, by the wing structure, by the mouth parts and the kind of metamorphosis they undergo. In complete metamorphosis such as is exhibited by the honey bee, butterflies, moths, flies, ants and beetles, there are four stages in the life history, namely, *egg*, *larva*, *pupa* and *adult*. From the egg there hatches a larva sometimes called a grub, caterpillar or maggot. This is a form greatly resembling a worm and indicates the annelid ancestry of the arthropods. These larvae feed voraciously and as they increase in size shed their old external coats, then form new exoskeletons in which they grow until they moult again. When the larva has attained full size it ceases feeding, finds some secluded spot, and spins a silk-like thread forming a cocoon, completely covering itself. It now ceases active movements but its form changes within the silken enclosure and the larva becomes a pupa. The pupa of butterflies is called a *chrysalis*. The internal and external changes continue until the adult or imago finally emerges. The pupa often bears no similarity to the larva or adults. After emerging from the pupa stage the adults never increase in size. In incomplete metamorphosis the larva develops from the egg. The larva grows and moulting occurs as often as necessary; wing pads appear and at later moults these appear larger until finally the adult insect appears. There is no quiescent stage in this type of metamorphosis. Some insects moult three times, others as many as twenty times in this type of development. Grasshoppers, crickets, cockroaches, lice, dragon flies all exhibit

incomplete metamorphosis. The young in various stages of moulting are known as *nymphs*. In many of these forms the nymphs pass a shorter or longer period in the water, emerging from it at the last moulting. Some insects have no metamorphosis at all but are very minute replicas of the adults when they emerge from the egg.

Classification of Insecta.—There are many orders of insects. A few of these are discussed here.

1. *Coleoptera.*—These are the beetles. The front wings are hard *elytra* or covers of the more filmy posterior wings. There is complete metamorphosis. They have biting mouth parts and many are carnivorous, feeding on insects which are harmful to crops. Some are herbivorous and injurious to crops. Some bore passageways through the wood of trees thus causing considerable damage. The males of the stag beetles have antler-like projections on the head. A beetle (*Scarabeus sacer*) was worshiped by the ancient Egyptians. One sub-group consists of leaf-eaters. Fireflies are beetles also. The lighting is under control of the nervous system. In all our common methods of illumination most of the energy used is wasted and dissipated in the form of heat. But in the firefly flashes practically no heat is generated. It is *cold* light. In some cases it has been shown that the flashes are connected with the process of mating. Hugh Smith describes the wonderful exhibition of the synchronous and simultaneous flashing of numberless fireflies at night in trees of a park in Bangkok, Siam. The effect was like myriads of electric lights automatically turned on and off.

Some beetles feign death when endangered. They lie on the *back*, with legs drawn up and are motionless. The click beetle is an example of this. If carefully watched it will be seen that all at once it " clicks " and flies into the air with a snap. If it lights on its back it will snap again and again until it lands right, when it will run away. Fat white grubs with brown heads live in the earth where they do considerable damage to roots of plants, pupate and emerge as large brown beetles that are very numerous around lights on May or June nights. These are the com-

mon June bugs. The meal worm, *Tenebrio molitor*, often found in flour and meal, is the larva of a beetle. It is kept in birdstores as food. Bark beetles cause millions of dollars damage to trees every year. The cotton boll weevil (Fig. 189) is an actual menace to the future of cotton growing in the South.

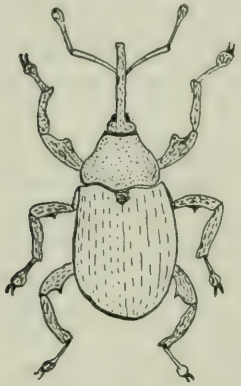

FIG. 189.—ANTHONOMUS —COTTON BOLL WEEVIL. (Bur. Ento., U. S. D. A.)

Tumble-bugs make a little ball of manure in which an egg is laid. The larva feeds on the dung. The Colorado potato beetle (Fig. 190) *Leptinotarsa* is very destructive to potatoes, feeding voraciously on the leaves. Arsenic compounds sprayed on the leaves of the potatoes kill the beetles and should be kept up during the growing season. Someone has stated that the potato beetle was unknown in the eastern part of this country until the growing of potatoes reached the West where this beetle occurred. It then worked its way east following the growth of potato operations.

2. *Hymenoptera.*—The metamorphosis is complete. There are two pairs of filmy wings. Ants, bees, wasps and gall-flies are common examples. Many of these insects live in colonies. There are a number of wild bees. In the case of the bumble bee, members of the colony, except fully developed females, die out in the fall. Each fertile female hibernates during the winter and in the spring starts a new colony which at first contains only infertile females. Later in the summer older females lay eggs that, with the help of the other workers, develop into functional males and females. The digger wasps (Fig. 191) excavate a nest in the ground. In this nest they deposit live caterpillars stung in such a way as to paralyze them. Then they lay eggs in the nest. The larvae of the wasp feed on these caterpillars. Some wasps kill their prey and tear it to pieces, feeding the young on choice bits. The mud-dauber-wasps build nests of mud under the eaves of buildings. This wasp also lays an egg

in the cell after she has filled it with paralyzed caterpillars to serve as a supply of food for the developing young. The solitary wasps do not live in colonies. Only males and females occur. They dig in the earth and build mud nests or bore tunnels in wood. The social wasps have a colony of males, females and sterile females, or workers. The young are not provided with stored-up food, but are cared for continuously. Some wasps build enormous nests of a paper-like substance. They scrape a small bit of wood from some exposed surface, work this up with saliva, and plaster it just where needed in construction of the nest. The workers build the nest. They hatch out of the first

FIG. 190.—LEPTINOTARSA—POTATO BEETLE.

(Bur. Ento., U. S. D. A.)

FIG. 191.—DISCOLIA—DIGGER WASP.

(Bur. Ento., U. S. D. A.)

eggs laid by the female. In the late summer or early fall males and females hatch from the eggs. The males fertilize the females and soon after die. Workers die when cold weather comes. Fertile females alone hibernate through the winter.

The Ants (Fig. 192) form a group of Hymenoptera of which no adequate description can be made here. Among them are found architects, builders, agriculturists, masons, and other trades. Some have a queen, some are soldiers, some keep slaves. They store up food for foodless months. The workers are sterile females. They have no wings. Sometimes many kinds of workers are present, each type modified especially for a certain kind of work. Some ants carry pieces of leaves into the nest. These are formed

into little balls on which a fungus grows, which is food for the colony. Some ant workers can make a honey-like secretion with which they feed the young. Some raise grass near their colonies and harvest the seed. Other ants have established profitable relationships with plant lice or *Aphids*. These aphids are carefully handled by the ants which place the plant lice where they may obtain food. Each aphid is provided with a pair of honey tubes near the tip of the abdomen. Through these a sweet liquid is exuded when the aphids are stroked in a certain way by the antennae of the ant. The ants are very fond of this food. It is stated that they carry aphids into their nests for the winter. The light oblong bodies seen in an ant nest are pupae or cocoons, being the last stage in development before the adult ant emerges.

FIG. 192.— MONOMORIUM —LITTLE RED HOUSE ANT. (Bur. Ento., U. S. D. A.)

The eggs and larvae are very small. If the nest is disturbed the workers rush to pick up these pupae in their jaws and hurry them to a safe place and do not hesitate to rush into danger to do this. On the whole their activities are machine-like. They do not stop to consider what they do. We say their acts are instinctive. Certain observations, however, indicate that some ants at times exhibit deliberation. All the activities of the ant seem to be directed toward the welfare of the whole colony. In August males and females from different nests of the same species undertake the nuptial flight during which mating takes place. After this the males die and the females, returning to the ground, pull off their wings and alone may start a new colony. A queen may lay thousands of eggs.

Most gall-flies are Hymenoptera. They are small insects. The females lay their eggs under the epidermis of young leaves of oak, witch hazel, willow, some grasses and other plants. They produce an irritating substance which causes a growth to take place. This may be round like a ball and

is known as a plant gall. Each type of gall insect produces a special type of gall. The larva feeds on the substance of the gall and pupates there. The mature insect eats its way out of the gall and flies away.

3. *Siphonaptera* (Fig. 193).—These are fleas which have no wings. They have sucking mouth parts, and metamorphosis is complete. They live among the hairs or feathers of animals or birds. Locomotion is by leaping. One type is common to cats and dogs. The human flea has a wide distribution. The rat flea transmits the dreaded bubonic plague from rats to man.

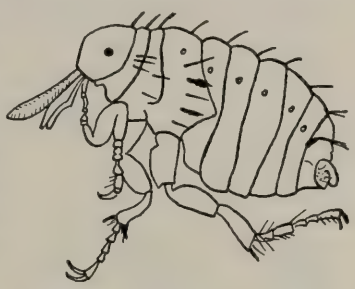

FIG. 193.—SARCOPSYLLA—HEN FLEA.

(Bur. Ento., U. S. D. A.)

4. *Diptera.*—These are the flies which have one pair of wings on the mesothorax, sucking mouth parts, and complete metamorphosis. The eggs of the mosquito are laid in water in a raft-like mass (Fig. 194). The larvae or wrigglers live in water. At the end of the abdomen is an air tube which is projected to the air above the water. The pupa lives in water also. When completely formed they leave the water. The larvae molt a few times, and become pupae. And these in a few days come to the surface, and the adult mosquito crawls out of the skin of the pupa.

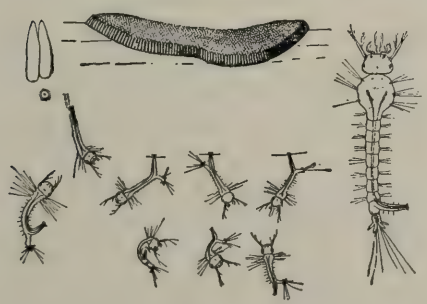

FIG. 194.—EGGS AND LARVAE OF CULEX MOSQUITO.

(Howard, Bur. Ento., U. S. D. A.)

Male mosquitoes do not suck blood, but rather the juices of plants. The females suck blood. Female *Anopheles Mosquitoes* transmit malaria. *Stegomyia mosquitoes* trans-

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mit yellow fever. The building of the Panama Canal by Americans after the tragic failure of the French was made possible by first ridding the region of the Stegomyia mosquito. This was accomplished by draining swamps and spraying a thin layer of oil over waters containing wrigglers. The latter are not able to project their breathing tubes through this oil film and hence they suffocate.

The Hessian fly causes a great deal of damage to wheat crops in this country. The female horsefly sucks blood. Bee flies resemble bees. The house fly (Fig. 195), *Musca* is a dangerous pest. It may transmit the germs of typhoid, tuberculosis, and other infectious diseases. It lays about 150 eggs in manure or garbage. These become larvae or maggots. In about a day they eat voraciously, in about a week become pupae, and in another week become full-fledged flies which will shortly produce another brood. Small flies or those larger than the house fly are not the young or overgrown specimens of the house fly, but mature adults of other species. Flies do not increase in size after developing from the pupa. There are many kinds of flies and many broods are produced each summer. Plagues of flies may be prevented by disposing of every trace of manure or animal matter on which they might breed. The passing of the horse and the coming of the automobile has meant the disappearance from our streets of great numbers of flies. Blow flies lay eggs on slightly decomposed meat that is exposed. A few hours of exposure may result in deposition of eggs. Bot flies of various kinds cause considerable losses among domestic animals, especially the horse. Eggs are laid on the hairs of the breast or the legs of the animal. The larvae are licked off by the horse and swallowed. Here they hatch and attach themselves to the wall of the stomach causing disease of this organ. Some other

FIG. 195.—COMMON HOUSE FLY—MUSCA DOMESTICA.

Pupa case, Adult, Larva. (Bur. Ento., U. S. D. A.)

species on being swallowed work their way through some part of the alimentary canal to the muscular tissue just under the skin where a " sore " may develop.

5. *Aptera* are insects without wings. There is no metamorphosis. *Lepisma* (Fig. 196) is a little silvery-white, dry-looking insect that eats the starchy matter on book bindings and clothing.

6. *Ephemerida.*—These are the may-flies (Fig. 197). Some people think they are mosquitoes. They have beautiful gauzy wings and are commonly seen over ponds in the spring evenings. The nymph lives for many months in the water and leaves the water as an air dwelling adult with

FIG. 196.—LEPISMA—SILVER FISH.

(Bur. Ento., U. S. D. A.)

FIG. 197.—CHIROTENETES—MAY FLY.

(N. Y. State Museum.)

wings. In the adult condition no food is taken as the animal mates, lays eggs, and dies all in a few hours after leaving the water.

7. *Odonata* are the dragon flies and others. Dragon flies are sometimes called darning needles. They have four large membranous wings. At rest the wings are held horizontally. The young dragon fly nymphs live in the water. The adults capture and feed voraciously on mosquitoes and so are useful to man. Many persons are needlessly fearful of the harmless and beautiful dragon flies.

8. *Isoptera* (Fig. 198).—White ants or *Termites* live in colonies. The colony contains a queen that deposits eggs, a winged male whose function it is to fertilize the eggs, and workers without wings. These build the nest, get the food,

care for and rear the young. Then there are wingless soldiers. Termites are more common in the tropical regions of Africa and South America. They may get located in a wooden building and proceed to construct tunnels in the timbers and in time cause its destruction.

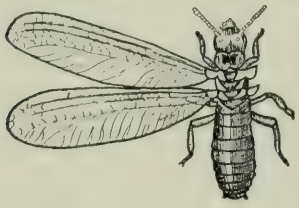

FIG. 198.—ADULT MALE WHITE ANT OR TERMITE.
(Bur. Ento., U. S. D. A.)

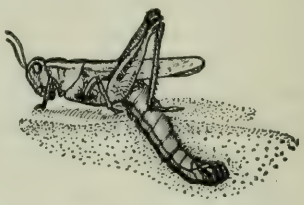

FIG. 199.—GRASSHOPPER DEPOSITING EGGS.
(Webster, Bur. Ento., U. S. D. A.)

9. *Orthoptera.*—These are the cockroaches, grasshoppers (Fig. 199) locusts, katydids, crickets and walking sticks. Cockroaches (*Blatta germanica*) were introduced to America from Germany. Their presence indicates careless housekeeping. Walking sticks (Fig. 200) have the appearance of dried twigs. This is a good example of protective resemblance. Not only do they escape notice, but even if attacked they are of no use as food and so practically have no predatory enemies. Locusts, or short-horned grasshoppers, have leaping legs and short antennae. They often do a great deal of damage to crops, especially the Rocky Mountain locust, *Melanopus spretus*. Linville recalls an incident in the summer of the 70's when a fine field of corn in the Missouri River Valley was visited about noon by millions of grasshoppers. In the afternoon nothing but the stumps

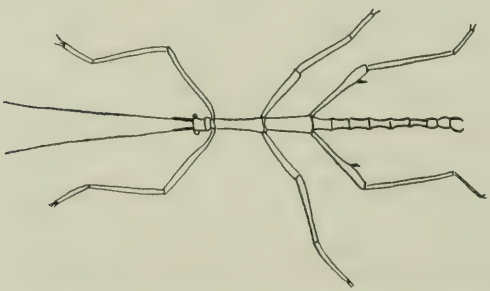

FIG. 200.—DIAPHEROMERA—WALKING STICK.

remained. They also ate every other green thing in sight. To-day, however, this Rocky Mountain locust is under better control. The eggs are laid in the ground and hatch out in the spring. Small wingless forms emerge. As they grow they moult until they attain adult size. Mole crickets live in burrows in the ground. The house cricket (*Gryllus domesticus*) lives in houses where its cheerful notes may be heard at times all through the winter.

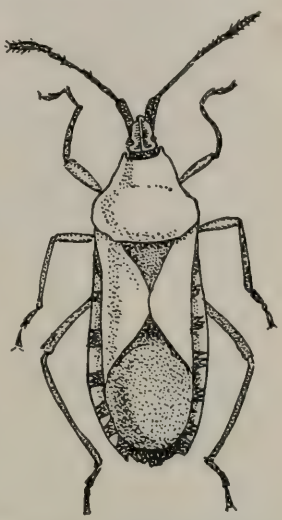

FIG. 201.—ANASA TRISTIS—SQUASH BUG.

(Bur. Ento., U. S. D. A.)

10. *Hemiptera.*—This order contains bugs (Fig. 201) lice and scale insects which are most destructive. They have sucking mouth parts and may have no wings or have four wings. Three species of lice infest man, the head louse, the body louse, the crab louse. They have no wings but claws for clinging to hairs. The mouth parts are fitted to pierce the skin and for sucking blood. One of the body lice transmits the dreaded typhus

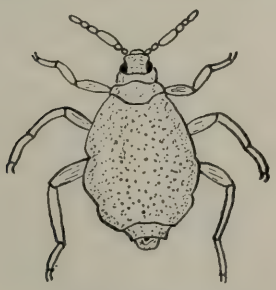

FIG. 202.—SCHIZONEUR.

Parthenogenetic female of Woolly Aphis of Apple. (Bur. Ento., U. S. D. A.)

FIG. 203.—ASPIDIOTUS—SAN JOSÉ SCALE.

Adult female with young. (Bur. Ento., U. S. D. A.)

fever. Persons free of this infected louse do not get this

disease. Unclean bodies and household surroundings are favorable to lice. Many animals are pestered with lice.

Aphids, or plant lice (Fig. 202), are very destructive to crops. Some live on roots of grape-vines, roots and twigs of apple trees, wheat and other cereals. Some consume leaves of such vegetable plants as the potato and turnip. During the summer the aphids are all females that lay eggs. These eggs develop into females without fertilization. This is called *parthenogenesis*. Several broods occur during the summer and an enormous number is produced. In the autumn males also appear and fertilize the eggs of the females. The last brood thus produced lives throughout the winter. Scale insects are extremely destructive. The San José scale (Fig. 203) came to this country from the Orient. The cottony cushion scale came near destroying the orange industry of California. A lady bug (Fig. 204) (beetle) from Australia was introduced to fight it. The lady bug feeds on the scale insects and thus helps to check the spread of the epidemic. It has been observed many times that when a strange form is introduced into a new country where conditions are favorable for its existence and where there are no enemies, it increases for a time until its very numbers destroy its available food supply or other animals combat it.

FIG. 204.—NOVIUS —AUSTRALIAN LADY BIRD.

(Bur. Ento., U.S.D.A.)

The *Cicada septendecem* (Fig. 205) lives underground as a nymph for sixteen years or so. Then it emerges from the ground, crawls up tree trunks to fresh young twigs, pierces the tender bark of these and deposits eggs. The twig beyond this point dies. In six weeks the young hatch, drop to the ground, dig their way into the earth and feed on organic matter or juices of roots and grow and moult until the seventeenth year, when they emerge as before.

Among the bugs should be noted the bedbug (Fig. 206) which feeds on the blood of man and poisons him slightly each time. It multiplies rapidly in a dwelling unless vigorously attacked. The chinch bug has caused enormous dam-

age to grain in the Mississippi Valley. Squash bugs eat squash and pumpkin plants.

FIG. 205—CICADA SEPTENDECEM—SEVENTEEN-YEAR LOCUST.

(Amer. Mus. Nat. Hist.)

11. *Neuroptera* have four membranous wings and biting mouth parts. The lace wing fly, *Chrysopa*, is called the aphis lion because it destroys enormous numbers of plant lice.

FIG. 206—AECIACUS—BED BUG.

(Bur. Ento., U. S. D. A.)

12. *Lepidoptera* consist of butterflies and moths (Fig. 207). They have four wings covered with scales. The wings are often beautifully colored. There is a long sucking tube which is coiled under the head when not in use. It is used to suck the nectar from flowers. Some of the caterpillars are very destructive to plants. Butterflies have knobs on the ends of the

antennae. Moths do not possess these knobs (Fig. 208). Moths fly by night, butterflies by day. When resting, butterflies often fold their wings vertically above the body. Moths when at rest have the wings spread out on the trunk of a tree or a rock.

Some moths are beautiful examples of protective resemblance. The upper surface of the wings, when the insect is

FIG. 207.—ATTACUS ATLAS—MOTH FROM INDIA.

The wing markings resemble the head of the Cobra. (Courtesy Amer. Mus. Nat. Hist.)

at rest blends in so perfectly with the surroundings as to escape notice. Some edible butterflies have the same appearance as other species which nauseate birds. This is called *mimicry*. The *mimics* are thus protected because they resemble the nauseating models. In the same way some harmless flies mimic bees that are avoided because of their stings. The green caterpillars of the cabbage butterfly (*Pieris rapae*) feed on cabbages. The eggs are laid in among the leaves of the cabbage. This pest came from

Europe about 1860 and spread all over this country from Canada. The gypsy moth (Fig. 209) (*Ocneria dispar*) came from Europe in 1868. Its caterpillars eat leaves and have been exceedingly destructive to trees in New England. It started its depredations in this country, in Cambridge, Mass. The Eastern States and especially New England spend huge sums of money each year in spraying trees to combat it. The adult female of the tent caterpillar (*Clisio-*

FIG. 208.—ACTIAS LUNA—LIFE HISTORY OF THE LUNA MOTH.

Upper row left;—larva; middle, pupa; right, cocoon. Lower row; left—male moth; right, female moth. (Amer. Mus. Nat. Hist.)

campa americana) lays its eggs on wild cherry trees. The caterpillars spin a cottony thread-like maze of fibers, the tents in which they develop. From this they emerge to strip the trees almost entirely of leaves, thus causing their death.

The army worm is the caterpillar of a moth (*Heliophila unipuncta*). The caterpillars feed on wheat, oats, corn and hay crops. Once established in a region they march on as an army from field to field and their effect is like a devastating conflagration. The codlin moth or apple worm lays its eggs on young apples. The larvae eat into the apples and greatly damage or destroy the apple crop. It has been

estimated that they do $10,000,000 damage each year. The clothes moth is small. Its caterpillars feed on furs, woolen cloth, feathers, etc. A perfectly satisfactory method of protecting clothing from their depredations has still to be found.

The silkworm moth (*Bombyx mori*) is now thoroughly domesticated. Over a hundred million dollars are invested in the silk industry in this country. Moths lay their eggs on cloth or paper and the larvae are fed on mulberry leaves. In forty days the larva spins a cocoon. This is made of one very long slender thread. It is loosely arranged on the outside, but more compact within. The pupa is killed by heating, the loose outside thread is removed, and then the inner part of the cocoon is unwound and this is woven into thread and cloth. One of the first bacteriological studies engaged in by Louis Pasteur was an investigation of a disease of the silkworm and he saved the silk industry of France.

FIG. 209.—OCNERIA DISPAR—GYPSY MOTH.

1, Egg masses; 2, Larva; 3, Pupa; 4, Female; 5, Male. (Amer. Mus. Nat. Hist.)

Considerable space has been given above to a discussion

of the Insecta. Not only are they the most numerous of all animals, but they are a most successful group. They vitally concern human welfare. They cause destructive human diseases. They kill domestic animals and destroy food plants and many of the products so necessary to civilized life. It is no exaggeration to state that insects cause in round numbers a billion dollar loss each year in the United States alone. We spend millions of dollars annually on our Army and Navy in protecting us against enemies which might exist. But in the Insects we have an actual enemy, maintaining a constant warfare, destroying our property, and at times killing our citizens. Why not invest in real protection against this actual enemy? Why not train entomologic soldiers to wage aggressive warfare against them? This is one illustration of the practical value of biological knowledge.

FIG. 210.—SCORPION (ARACHNIDA).
(Amer. Mus. Nat. Hist.)

Class III. Arachnida.—Another class of Arthropoda are the *Arachnida*. This class includes spiders, ticks, mites, scorpions and king crabs. They have no antennae, no true jaws, but the first pair of appendages are nippers. The body has an anterior part, a cephalothorax and an abdomen. Most of them have poison glands. Human beings may be seriously poisoned by certain small spiders. Spinning organs of spiders are three pairs of appendages called *spinnerets*. Through many fine tubes in these, a fluid formed in silk glands passes out and hardening in the air forms a thread. An orb web is formed in the following way: The spider selects a place in which to construct a web. Then it attaches a thread to a twig above and drops off the twig, spinning the thread as it goes. It connects the first twig to another. Then from a point

in this thread others are spun out in radiating directions and securely fastened. After these threads have become dry and smooth the spider spins a sticky spiral thread. It now stands watch until a fly or some other insect gets caught in the meshes. The spider rushes out and spins threads around its prey until the latter is helpless. Some spiders do not spin webs, but hunt for their prey or lie in wait for them.

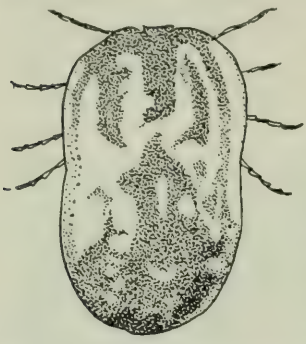

FIG. 211.—MARGAROPUS—TEXAS FEVER CATTLE TICK.

Adult female — engorged. (Bur. Ento., U. S. D. A.)

Scorpions (Fig. 210) are large, long segmented arachnids which capture insects with their claw-like appendages and tear them apart with the appendages about the mouth. They paralyze larger animals with the sting on the tail. The poison is harmless to the scorpion. Daddy-long-legs have very long legs enabling them to run rapidly in search of small insects. "Chiggers" get on the bodies of men and animals from plants. They burrow into the skin, producing sores.

The cattle tick (Fig. 211) clings to the skin of cattle with the mouth parts and sucks blood. The adults drop to the ground where eggs are deposited by the thousand. When these hatch the young climb up on stalks of grasses and attach themselves to the cattle when they brush by. It is now known that they transfer a *sporozoan* from the blood of one animal to another. This parasite produces the deadly Texas fever, which has caused an annual loss of millions of dollars a year in the United States. For many years nearly three quarters of a million acres of grazing land was

FIG. 212.—LIMULUS POLYPHEMUS. KING CRAB.

quarantined against cattle raising because it was tick infested.

The king-crab (Fig. 212), *Limulus polyphemus*, is found in shallow sea water on sandy bottoms along the Atlantic Coast from Maine to Central America. It is the largest Arachnid and is unique in being a marine form. It also burrows in the sand and in the spring it breeds near the shore. Limulus breathes by means of gills which are plate-like structures on certain appendages while there are locomotor appendages on the other segments.

Patten maintains that the king-crab is related to the ancestors of the Vertebrates.

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CHAPTER XVIII

PHYLUM X. CHORDATA. SUB PHYLUM I AND SUB PHYLUM II. CLASSES I, II AND III

This phylum includes *Fishes, Amphibia, Reptiles, Birds, Mammals*, and some other forms which, at first sight, would not be included with the above examples. These animals are *bilaterally symmetrical.* They possess a definite anterior, posterior and dorso-ventral differentiation. They have a body cavity and there are indications that the body is segmented. The various tissues and organs develop from three embryonic or germ layers: ectoderm, endoderm and mesoderm. All the animals included in this phylum possess three characteristic structures.

First of all, the body is supported by a longitudinal rod-like structure called a *notochord.* This extends the length of the body under the dorsal mid-line. The phylum gets its name from the notochord.

Second, that portion of the mouth behind the jaws, called the *pharynx*, possesses pairs of vertical slits on each side. Membranous gills border these slits.

Third, the central nervous system is a hollow cylindrical mass of nerve cells and fibers, dorsal to the intestine and dorsal to the skeletal axis. In most Chordates the anterior end is organized into a large and chief nerve center, a *brain.*

These Chordates are divided into two subphyla, namely the *Prevertebrates* and *Vertebrates.*

Sub Phylum I. The Prevertebrates are small animals with more or less clearly defined chordate characteristics. Three examples are noted.

A. Hemichorda.—Balanoglossus (Fig. 213), a worm-like form about 15 cm. long and 0.5 cm. in diameter, lives in the sand or mud along the seashore. Three-body regions

are evident: (*a*) *proboscis,* (*b*) *collar,* (*c*) *trunk.* It has a long alimentary tract. The obvious claim to relationship with the chordates is the many pairs of gill slits and gills at the anterior end of the alimentary tract. The nervous system is a diffuse network under the epidermis with thickenings along the mid-dorsal and mid-ventral line. Finally, a forward rod-like prolongation from the anterior end of the mouth extending dorsally from the mouth into the proboscis is said to be a notochord. Balanoglossus possesses a larval form called a *Tornaria.* Because of the resemblance of the Tornaria with certain Echinoderm larvae, some authors believe that Balanoglossus indicates a genetic relationship between Echinoderms and Chordata. But in other respects the Tornaria larva resembles certain larvae of Annelids and because of this it is believed by some writers that *Balanoglossus* had an Annelid ancestor. This seems the more plausible theory. The adult is Annelid-like in a number of respects.

FIG. 213.—BALANOGLOSSUS, A HEMICHORDATE.

B. Tunicata or Urochorda.—A common form along the Atlantic Coast is *Molgula manhattensis.* Tunicates live in the sea. (Fig. 214.) They were formerly classified with mollusc-like animals until 1866, when Kowalesky showed their chordate characteristics. They are free swimming or attached sac-like forms. They are called *Tunicates* because the soft internal parts are protected by a tough outer tunic. They are sometimes called sea squirts because the animal squirts water through two tubes at the free end when irritated. Water normally enters the animal through one of these tubes and leaves the body by the other. Oxygen and food is obtained from the water, and carbon dioxide, excretions, feces and reproductive cells leave by the other tube. The mouth leads into a large pharynx which is perforated with a great many gill slits. The water coming into the pharynx passes out through these gill slits into the

atrial chamber and thence out of the animal through the exhalent or atrial opening. At the base of the pharynx is the opening to the rest of the alimentary canal, which is bent around itself, ending in the anus in the atrial cavity near the atrial opening. The simple tubular heart is located near the alimentary tract at the lower end of the pharynx. The heart behaves in a peculiar way. First its contractions pass in one direction for a while, then they reverse themselves, moving in the other direction. The blood is colorless. The animals are hermaphrodite. The simple sex glands lie in the loop of the intestine. Testis and ovary mature at different times. Goniducts pass alongside the alimentary tract and open near the anus.

FIG. 214. — CYNTHIA, A TUNICATE, UROCHORDATE.

Tunicates in their adult condition do not appear to be Chordates. The sessile adult condition is preceded by a larval free swimming tadpole form. This has an enlarged anterior end behind which is a vertically compressed tail. This tadpole shows bilateral symmetry— antero-posterior differentiation and dorso-ventral differentiation. It shows plainly all three chordate characteristics. First, the mouth leads into a pharynx with perforated gill slits. Second, an elongated notochord extends back to the tip of the tail. Third, above the notochord is the nerve chord.

There are some compound Ascidians where many individuals are surrounded by a common tunic. In some forms the individuals have a common circulatory system. Ascidians can reproduce asexually by budding.

C. Cephalochorda, are often called lancelets from the body form. Some authors regard these as offshoots from old vertebrate ancestors, others regard them as degenerated early Vertebrates. *Amphioxus lanceolatus* (Fig. 215) is a common form. It is bilaterally symmetrical, it has antero-posterior and dorso-ventral differentiation, a body cavity and tubular intestine. It is two inches

more or less in length. Alive, it is whitish in color. On the side of the body can be seen plainly the segmented "V" shaped muscle masses or myotomes. Just back and under the pointed front end of the body is a circular fringe of tentacles. At the bases of these is the mouth. The mouth leads into a large laterally compressed pharynx. This is perforated with many gill slits provided with gills. Water comes into the mouth, passes out through the gill slits into the atrial chamber and out from this through the *atriopore* somewhat back of the middle on the ventral side just in front of the ventral fin. The intestine passes back from the pharynx ending in the anus on the left side behind the atriopore. Near the beginning of the intestine is a forward directed blind pouch running along the right side of the pharynx and this is called the *liver*.

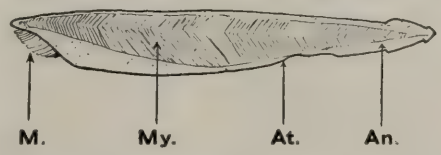

FIG. 215.—AMPHIOXUS, LANCELET, CEPHALOCHORDATE.

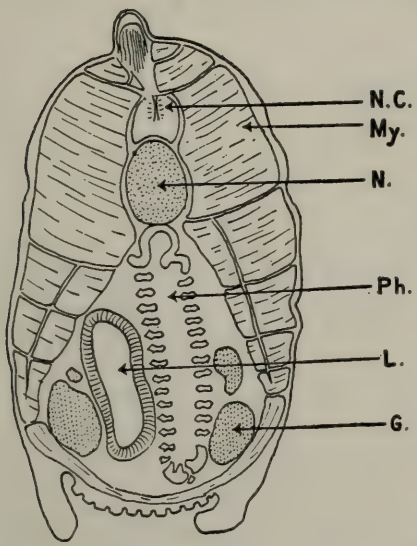

FIG. 216.—CROSS-SECTION AMPHIOXUS.

N.C., Nerve cord; *My.*, Myotome; *N.*, Notochord; *Ph.*, Pharynx; *L.*, Liver; *G.*, Gonad.

Amphioxus possesses a dorsal blood vessel—in which the blood flows posteriorly (as in Vertebrates) and a *ventral vessel* in which the blood flows forward. From the ventral vessel blood flows through afferent branchial arteries to the gills, thus ensuring oxygenation of the blood, thence from capillaries of the gills to efferent branchial arteries, to the

dorsal vessel. The dorsal and ventral vessels have branches. The *notochord* is a cylindrical axis (Fig. 216) extending from the front end to the rear of the animal, along the dorsal midline. There is a central nervous system, a cord-like structure lying above the notochord and hence above the intestine (compare with the Earthworm and Vertebrates). It is slightly enlarged at the anterior end (brain). The sexes are separate. There are twenty-six pairs of gonads along the wall of the atrial cavity from segments ten to thirty-five. Eggs and sperm are liberated into the atrial cavity and pass out through the atriopore into the water where fertilization takes place. Amphioxus is a classic form to the biologist. The tadpole of Tunicates and the adult Amphioxus resemble each other in that both possess a much perforated pharynx, an atrial chamber, an elongated notochord and dorsal nervous system. It is thought that they had a common ancestry.

Sub Phylum II. Vertebrata

All of these forms are larger and more highly organized than the prevertebrates. The embryos possess a notochord which is later displaced by an axial segmented backbone composed of separate pieces called *vertebrae.* In the lowest groups these vertebrae are composed of cartilage, in the higher groups of bone. They, of course, possess the other chordate characteristics, namely, dorsal nervous system and pharyngeal gill slits. Lamarck called all animals which did not possess a backbone *Invertebrates.* This division of the Animal Kingdom into Vertebrates and Invertebrates is not advisable because of the *number* of distinct types of body plan in the Invertebrates. But the influence of this early division of Lamarck is still felt. The greater similarity between the structure of the human body and all the other Vertebrates is also partially responsible for this.

The Vertebrates may be divided into seven classes:—(1) *Cyclostomata,* (2) *Elasmobranchii,* (3) *Teleostomi,* (4) *Amphibia,* (5) *Reptilia,* (6) *Aves,* (7) *Mammalia. Pisces* is a general name for the first three groups.

Class I. Cyclostomata (round mouth).—An example is *Petromyzon* (Fig. 217). These animals resemble eels in form. They have no jaws nor paired appendages. The notochord is well developed in the adult. The head and gills are supported by a cartilaginous basket. The skeleton is cartilaginous. There is no atrial cavity—the sides of the pharynx possess external gill openings. The skin is soft and very slimy. The animals possess well-developed eyes, olfactory sacs and an internal ear. The skin is provided with sense organs of touch. The animal has a heart behind the head on the ventral side. There are arteries, veins, and capillaries present. It has a brain resembling that of embryos of higher Vertebrates. There is no distinct stomach

FIG. 217.—PETROMYZON, LAMPREY EEL.

(U. S. Bur. Fisheries.)

present. There is a liver but often no bile duct connecting it with the intestine. The muscular system consists of serially repeated zigzag shaped myotomes. Kidneys are alongside the mid-line of the dorsal body cavity. An excretory duct carries urine back into a common urinogenital chamber. The sexes are separate but eggs are sometimes present in the testis of the male. The sex cells break out of the gonads into the body cavity and from this through a pair of genital pores into the urinogenital sinus and thence into the water by the urinogential aperture. There are two types of Cyclostomes: (*a*) Hag fishes (*Myxine*) and (*b*) Lampreys (*Petromyzon*). The hag fishes are marine while the lampreys live in fresh and salt water.

Class II. Elasmobranchii.—These are sharks, skates and dogfishes. Some authors include them with the true

fishes. But nevertheless they all form a distinct class differing from other fishes.

The study of a dogfish (*Squalus*) (Fig. 218) illustrates the general features of these animals. The body is fusiform in shape, larger in the anterior region. In front is the projecting snout. Just behind this and underneath is the mouth. At the posterior end the body is vertically compressed and ends in the caudal fin which is asymmetrical. The dorsal lobe is much more elongated than the ventral. The tail and caudal fin form the principal means of locomotion. This type of fin is called *heterocercal.* It is correlated with the ventral mouth. Propulsion by this type of fin would send the animals downward. And these are often bottom

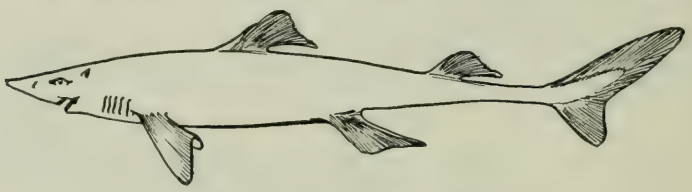

FIG. 218.—SQUALUS—SPINY DOGFISH.

(U. S. Bur. Fisheries.)

feeders. The body is covered with small *placoid scales.* These scales have a round flat base from which rises a curved tooth-like spine extending posteriorly. The body of a placoid scale is composed of dentine. Inside is a pulp cavity. The pointed tip is covered with enamel. In all these respects it is like a tooth. They might be called skin teeth. It is believed that the teeth of all Vertebrates are modified placoid scales which in Elasmobranchii were found all over the external surface and inside the mouth, but which in higher animals became limited to the mouth. On the lateral surface of the head are the eyes. The eye has a third lid in addition to the two usually found. This, the nictitating membrane, can be drawn across the eye from the inner corner. Back of the eyes are six pairs of openings. Just behind the eyes are the spiracles. These lead into the pharynx. Through them water for breathing passes when the mouth

is closed. Just in front of the anterior paired fins and laterally are found the gill slits. Associated with the gill slits are the membranous gills. Water passes out from the pharynx through the gill slits, bathing the gills. In this process the blood in the capillaries of the gills takes up oxygen out of the water and gives up CO_2 to the water. The nostrils are openings leading to blind sacs just in front of the mouth.

Two kinds of fins are present, paired and unpaired. The latter are median dorsal and ventral projections. They are the more primitive and they alone are found in Amphioxus and Cyclostomes. In Squalus there are two dorsal fins and one caudal fin. Two pairs of horizontal lateral fins are present. The forward pair are called pectoral fins while the posterior are the pelvics. Each pair is attached to a cartilaginous ring inside the body; the pectorals being attached to the pectoral girdle and the pelvics to the pelvic girdle. The bases of the pelvic fins enclose the cloaca terminating in the anus, the slit-like external opening of the alimentary tract. Underneath the skin are the zigzag-shaped segmentally repeated muscles or *myotomes* showing similarities to those of Amphioxus and Cyclostomes. In the region of the paired fins the body muscles are modified to move these fins. The skeleton is cartilaginous. It is divided into the axial skeleton and appendicular. The axial skeleton consists of the skull and the segmented vertebral column. The embryonic notochord still persists in between the hour-glass shaped vertebrae. The skull consists of a cartilaginous box-like cranium enclosing the brain and the visceral skeleton. The latter consists of a series of cartilaginous bars forming the jaws and supporting the gills. The embryonic skeleton of higher animals is in many general respects similar to that of the dogfish.

The digestive tract is a little longer than the body. This shortness is correlated with the concentrated food of Elasmobranchs. (Fig. 219.) Behind the mouth with its rows of teeth is a large space, the pharynx, from which open the spiracles and gill slits. The pharynx leads into the short wide oesophagus which opens into the " V " shaped stomach.

At the intestinal end of the stomach is a valve (*pyloric sphincter*) which controls the discharge of food from stomach to intestine. The small intestine is very short. Behind it is the large intestine, inside of which is a central axis from which a spiral membranous shelf runs to the outer wall. This is called a spiral valve. Thus the internal surface of the intestine is increased. Attached to the hinder end of the intestine is the rectal gland.

The liver consists of two large lobes. Ducts from these lobes carry the liver secretions into the common bile duct

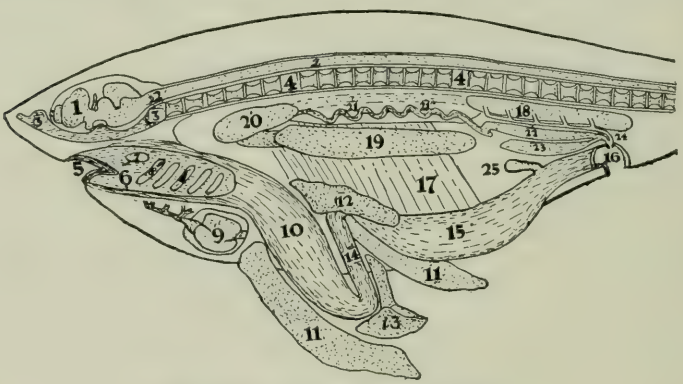

FIG. 219.—ANATOMY OF DOGFISH.

1, Brain; 2, Spinal cord; 3, Skull; 4, Spinal Column; 5, Mouth; 6, Pharynx; 7, Spiracle; 8, Gill slit; 9, Heart; 10, Stomach; 11, Liver; 12, Pancreas; 13, Spleen; 14, Intestine; 15, Large intestine; 16, Cloaca; 17, Mesentery; 18, Kidney; 19, Testis; 20, Epididymis; 21, Vas deferens; 22, Seminal vesicle; 23, Sperm sac; 24, Urino-genital papilla; 25, Rectal gland. (Modified from Marshall.)

and so into the intestine. A side branch leads to the gall bladder imbedded in the liver, in which bile is stored. Along the left bend of the stomach is the dark red spleen. Farther on and extending between the pyloric end of the stomach and the intestine is the whitish *pancreas*. The large intestine opens behind into the *cloaca*. Lying against the dorsal wall of the body cavity are the gonads. These are elongated white testes in the male. In the mature female the developing eggs in the ovary may be seen. The oviducts are long tubes lying against the dorsal wall of the body cavity. They join anteriorly under the intestine and there is a common

opening through which the eggs enter. The eggs pass back through the oviducts into the cloaca and hence to the outside. The kidneys are narrow elongated organs which lie on each side of the dorsal mid-line covered up with peritoneum, the membrane which lines the body cavity. Urine passes from the kidneys through ducts called ureters to the cloaca. The testis of the male is connected with the cloaca by sperm ducts. Connected with the pelvic fins of the male dogfish are a pair of processes called *claspers* used in mating. It is evident that the cloaca receives wastes from the intestine, from the kidneys and reproductive cells from the gonads (that is, ovaries and testes).

The heart is ventral to the pharynx. It is located in the pericardial cavity just above the ventral portion of the pectoral girdle. A canal connects the pericardial chamber with the abdominal cavity. The heart consists of a single auricle and ventricle. The course of circulation is briefly as follows: The venous blood from all over the body is emptied into a large thin-walled sac, the sinus venosus, posterior to the auricle and thence into the auricle. This contracts and pumps the blood into the thicker, muscular ventricle. When this contracts, a valve closes between auricle and ventricle. From the ventricle the blood passes forward through the conus arteriosus and thence into the ventral aorta in the floor of the mouth. From this ventral aorta the blood flows through afferent branchial arteries to the capillaries of the gills. Here the blood is oxygenated and gives out CO_2 to the water. From the gill capillaries the blood passes up through efferent branchial arteries to the dorsal aorta and from this is distributed to all parts of the body. The afferent and efferent branchial arteries are called *arterial arches* because they form arches around the pharynx.

The dogfish has a well-developed nervous system. There is a brain, spinal cord, cranial or brain nerves and spinal nerves. The brain possesses two very large olfactory lobes, a pair of cerebral hemispheres, a small diencephalon, a pair of optic lobes, a cerebellum, and medulla.

General Account of Elasmobranch.—They have a carti-

laginous skeleton with traces of notochord still persisting, placoid scales, spiral valve in the intestine, claspers in the male. They have a heterocercal tail and ventral mouth. The heart contains venous blood. Fertilization is internal. Some forms lay eggs (*oviparous*) protected by horny egg cases. Others bring forth living young (*viviparous*). The eggs in most cases are large and well stocked with food (yolk). In *Mustelus* there is a placenta-like connection between the yolk sac of the embryo and the uterus of the mother.

The word " shark " (Fig. 220) is a general name which

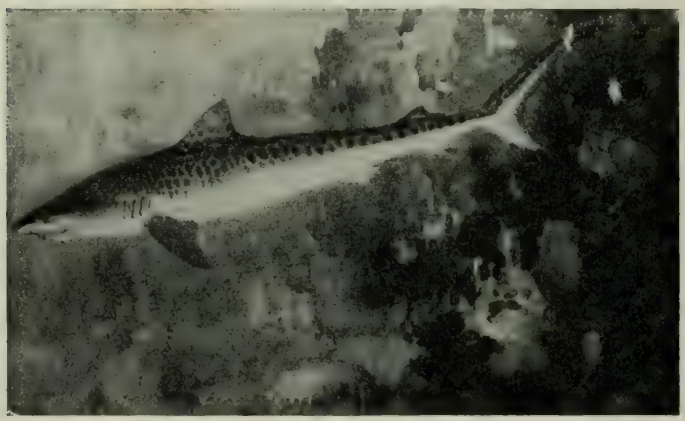

FIG. 220.—GALEOCERDO—TIGER SHARK.

(From a painting by Charles R. Knight. Courtesy Amer. Mus. Nat. Hist.)

includes forms like the dogfish which are sometimes called dogfish sharks. True sharks have large triangular-shaped teeth with notched edges adapted for grasping and cutting. Dogfish and skates have rows of diamond-shaped flat teeth. *Carcharodon carcharius* is a large white shark which lives in warm waters. It is sometimes thirty feet long and will attack man. When sharks are hungry they vigorously attempt to secure any kind of animal food available. The hammer-head shark has two lateral flat prolongations on the head. On the edges of these are the eyes. There is one fresh-water shark living in a lake in Nicaragua.

Sharks live more in the open sea than skates and rays, which are shore-dwelling forms.

Skates (Fig. 221) and rays are flattened dorso-ventrally

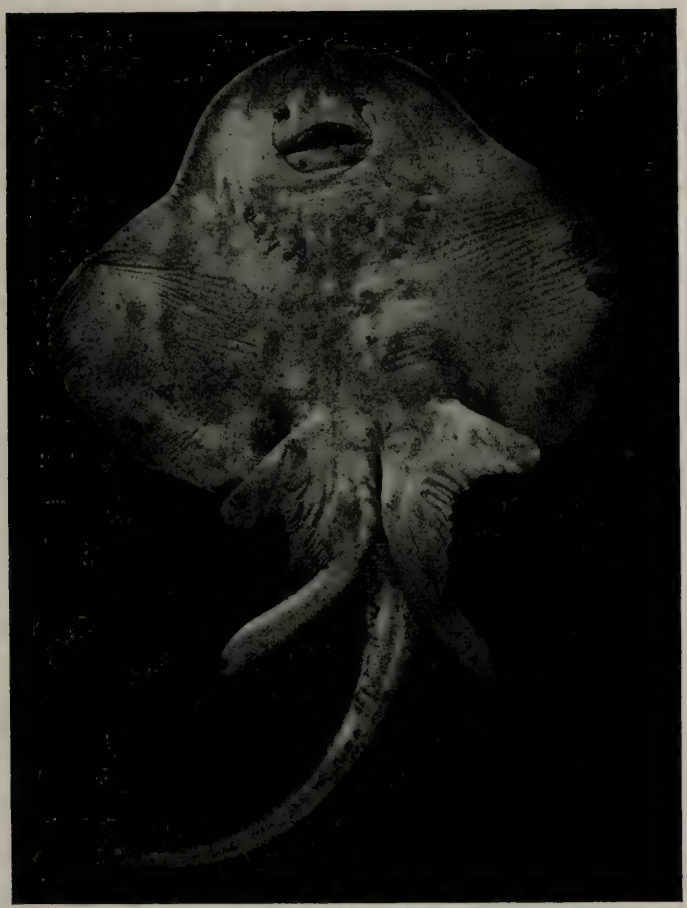

FIG. 221.—RAIA—COMMON SKATE. VENTRAL VIEW.
(Amer. Mus. Nat. Hist.)

and dwell on the sea bottom. The sawfish is a tropical form from ten to twenty feet in length. A flat, narrow, forward prolongation of the snout bears teeth which are effective in defense, for the animal wields it with powerful side strokes.

The torpedo possesses vertical bundles of special muscles, on either side of the head which act as electric batteries. Any animal in contact with this battery receives a powerful shock. The sting ray has a long whip-like tail. On the tail is a sharp spine which carries poison into the wounds it makes.

Some sharks attain a length of forty-five feet. The food of these animals consists of fishes, squid, crabs, lobsters. Dogfish and sharks cause great damage to the nets of fishermen. It is also believed that they are responsible for the decrease in numbers of lobsters. In recent years, however, dogfish do not seem to be as plentiful as formerly. Skates, dogfish, and sharks are used to a certain extent for food. One attempt was made to can dogfish. In time, however, a strong ammonia odor developed, rendering the product unfit for food. Dogfish muscle is rich in urea which easily breaks down into ammonia. The livers of all the Elasmobranchs are valuable as a source of oil and formerly the outer layer of skin containing the placoid scales was used as an abrasive. Now there are better and cheaper abrasives. Watch cases and sword handles were covered with this shagreen. Methods have been discovered of separating the scale-bearing part of the skin from that underneath and the deeper layers tan into good leather. The only obstacle to the development of this industry is the difficulty in securing skins. The concentration of the blood of Elasmobranchs is about the same as that of the sea water in which they live. This is also true of the marine invertebrates. An exception to this is seen in marine bony fish, whose blood is less concentrated. The blood of all higher animals is more like that of bony fish in this respect.

Class III. Teleostomi.—These are the True Fishes such as trout, perch, bass, cod (Fig. 222), mackerel, etc. They have many of the characteristics of the Elasmobranchs. Some of the important differences are: (1) Bony skeleton for which reason they are called *Teleostei* (all bone); (2) the mouth is terminal; (3) the tail is symmetrical, that is, the dorsal and ventral lobes are equal; (4) the body is covered with flat scales; (5) the gills are covered with a flap

called the *operculum:* (6) the fins of most are supported by jointed fin rays; (7) most of them have a swim bladder or air sac dorsal to the gut and connected with it in some forms; (8) the eggs are smaller and are greater in number; (9) most of them are oviparous although some are viviparous. The Elasmobranchs are present-day representatives of more ancient fish-like forms than Teleostomi. The latter are a more specialized offshoot from the main line of evolution while the Elasmobranchs are nearer this imaginary line.

FIG. 222.—GADUS, THE COD.

(U. S. Bur. Fisheries.)

Sometimes both Elasmobranchs and Teleostomi are placed in one general, all inclusive group—*Pisces.*

General Notes on Fishes.—*The Form of the Body.*—Varies greatly. Most of the important food fishes have a fusiform body. Eels have a snake-like body. The butterfish is greatly compressed. Flounders have flat compressed bodies, but they swim with the lateral side down. The skull is twisted with both eyes on one side of it. Puffers can inflate themselves with air or water so that they are almost globular.

Body Covering.—The bodies of eels (Fig. 223) and catfish are smooth. Sturgeons have bony plates on the surface. Most fish possess flat scales. These are of two types: *cycloid,* in which the posterior edge is smooth; *ctenoid,* in which the

edges are notched or toothed. Scales show rings, a close study of which reveals the age of certain fish and rate of growth.

Fins.—These vary in number. The usual arrangement is a dorsal fin on the back, the caudal fin at the tail, and the anal fin near the anus. These are unpaired fins. Below the shoulders are the pectoral fins and the pair on the abdomen are the pelvics. The dorsal fin of the eel continues back to the caudal and this extends forward along the ventral side of the tail which is a reversion to the primitive

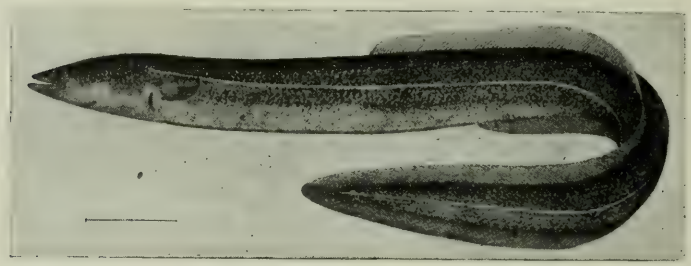

FIG. 223.—ANGUILLA—COMMON EEL.

(U. S. Bur. Fisheries.)

type of fin. It has no pelvics. When fins are lost in combat or accident they regenerate again. The paired fins are looked upon as related to the ancestral condition of limbs of land Vertebrates. The caudal fin is the principal organ of locomotion. It is a propeller. The mechanical principle involved is similar to sculling a boat. The other fins are used in guiding the fish. Shark suckers or remoras have very specialized fins. They attach themselves to sharks by means of a sucker on the top of the head and are thus carried about by no effort of their own. This sucker is a much modified, dorsal median fin. The upper surface of their bodies is lighter in color than the belly, which characteristic is just the opposite of other fishes.

The mouth is usually of moderate size and terminal. It is very small in pipe fishes. The goose fish (Fig. 224) has a very large mouth. It lies in wait in the mud and at favor-

able opportunities suddenly opens its capacious mouth when numbers of small fishes are carried into it with the rushing water. Garfish have a long snout and the mouth extends from the tip of the snout to the eyes. Teeth vary in size, shape, number and location in the mouth; all depending on the nature of the food. If the food consists of other

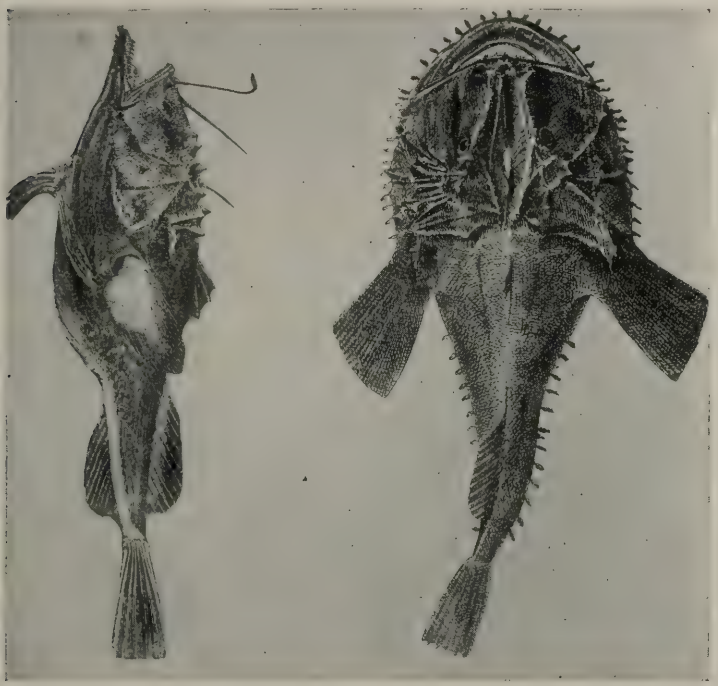

FIG. 224.—LOPHIUS, GOOSE FISH OR ANGLER.

(U. S. Bur. Fisheries.)

fish, the teeth are sharp and pointed, used in holding the prey until it can be swallowed. If the food consists of microscopic algae the teeth are very small. The teeth of some fish are sharp and chisel-like, and are used in cutting out pieces of flesh. Teeth are also strong and rounded, used in crushing.

The eye is usually on the upper lateral surface of the head

and directed toward the light and is probably not an acute sense organ. Some cave fishes have lost the sense of vision, and have even lost their eyes. The ear is within a chamber in the skull, and, like the eye, is connected with the brain by means of nerves. Disturbances in the water are communicated to this sense organ through the skull. There is no external ear. The nostrils are pits in the snout. They do not communicate with the mouth except in Lungfishes. The olfactory sense cells are connected with the olfactory lobes of the brain. These sense organs are probably used to detect presence of food or other substances in the water. Many fishes have a " lateral line " running alongside the body from head to tail. Tubes are located in this and these are connected with nerves. These are called *lateral line sense organs.* They are supposed to aid in the sense of hearing and possibly smell and taste. Some fish have antenna-like projectives from the head called *barbels,* which are special organs of touch. Sometimes the fins possess barbels.

The gills consist of bony arches with external fringes of reddish membranes. The oxygen is absorbed through the membranes into the red blood corpuscles by the hemoglobin in the latter. The lungs of air breathers accomplish a similar result. Most Teleostomi have five pairs of gill arches. Many Teleostomi have a membranous sac in the body cavity along the dorsal mid-line. This is the *swim bladder.* It is filled with air (gas) secreted by cells along its walls. It usually does not serve as a lung, but rather as an organ of equilibrium. In moving near the surface the body is made more buoyant by an inflated swim-bladder. Flounders have no swim-bladders. The bladder is connected with a duct to the pharynx of some fishes. The grunts of the croaker may be heard under as well as above water. Expulsion of air from the swim-bladder is associated with this.

Carnivorous Teleostomi have a short alimentary canal. Herbivorous fish have a long intestine and connected with the stomach are a number of blind tubes called *coeca* which are probably secretory.

Colors of fish show wide variations. The brilliantly colored forms are found in tropical seas. In some cases the colors are protective. In others it would seem that the fish is made more conspicuous. Flounders imitate the bottom on which they rest. On white sand they are lighter, on a dark background, darker. Moreover, they can assume various colors if the color of the background is changed. Sometimes the sexes have different colors and in some the male changes color during the breeding season.

Food.—The cod eats all kinds of food available. Some fish feed on Molluscs and Crustaceans only; some on green Algae; some, like the shad, on minute Crustacea; some on minute Algae. Some large fish feed continuously on microscopic organisms, others at times swallow fish almost as large as themselves. It has been stated that bluefish have been known to swallow so much as to cause the body to burst. Some fish feed on other fish, which in turn feed on lower animals, which in turn feed on plants. Both plant and animal foods must be present in water to support a varied fish population. There is an interdependent relationship.

Migration.—Many fish *migrate;* some for short distances, others on long journeys. These migrations seem to depend on the development of the breeding organs, the necessity for food and the temperature of the water which varies with the season of the year. Many return year after year to the same breeding grounds. Some forms which mature in the sea go long distances to the head of fresh-water streams to spawn. The shad and alewife breed in fresh waters. The salmon overcomes great obstacles and, to spawn, may travel over a thousand miles to the headwaters of the stream in which it was born. The eel which spends most of its life in fresh waters will travel great distances to very deep waters of the ocean to breed. Mackerel travel in great schools long distances, near the surface of the ocean, after food.

Many marine fishes go from colder shore waters to deeper and warmer waters in winter. Probably food has something to do with this. The menhaden travels long distances north in spring and south in winter. Many unexplained phenomena connected with the distribution of fishes occur

from time to time. For example, menhaden had been rare on the coast of North Carolina for a number of years, but suddenly reappeared in great numbers in 1917. The tile fish (Fig. 225), an important food fish, was abundant off the coast of New England for many years, then absolutely disappeared only to reappear several years later.

Information concerning former geographical and geological conditions may be obtained from a study of fish distribution. For example, some forms almost identical

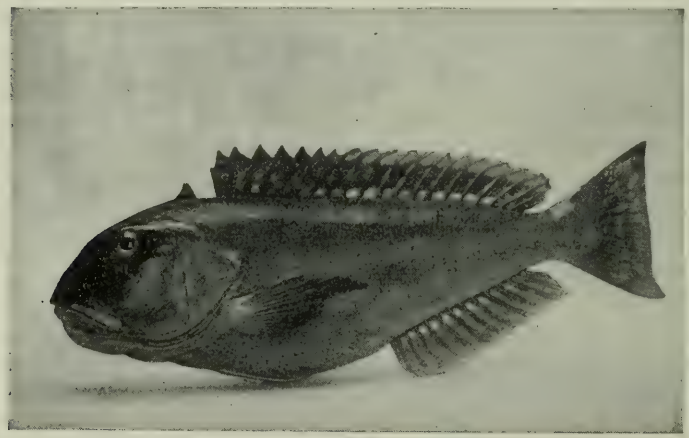

FIG. 225.—THE TILE FISH, LOPHOLATILUS.

(Amer. Mus. Nat. Hist.)

have been found along the Atlantic and Pacific coasts of the Isthmus of Panama. The evidence indicates that a natural interoceanic passageway connected these waters in recent geological times. On the other hand, there are indications that the closure of this passageway produced changes in other species which were no longer able to pass back and forth.

Spawning.—Many fishes *spawn* during the spring or early summer. The cod, menhaden, salmon, winter flounder and trout spawn in the fall or winter. Some have definite spawning grounds where food for young fish will be abundant. In most fish the spermatazoa are discharged from the male who

swims near the female as she discharges the eggs. In some cases no care is taken of the eggs. In the pipe fishes the fertilized eggs are transferred to a pouch on the ventral surface of the body of the male where they are carried until hatched. Some male catfishes carry the developing eggs and even the young in a pouch in the mouth. The herring and other fishes lay eggs heavier than water. They develop on the bottom. The cod produces floating or pelagic eggs. Fish which produce large eggs have fewer eggs. The marine

FIG. 226.—MELANASTOMIAS, DEEP SEA FISH.

Found N. W. of Sumatra at 1024 meters depth. (Amer. Mus. Nat. Hist.)

catfish, *Felichthys*, produces about fifty eggs at a time. The cod may spawn over nine million during a single season. Some eggs hatch in less than a day's time. A month is needed in the case of salmon. Some deep sea fish have *luminescent* organs. (Fig. 226.)

There is considerable evidence that wholesale fishing operations have reduced the numbers of certain commercial fishes. The establishment of hatcheries in which the young can be more safely reared during the period of greatest mortality may help somewhat. Fish should not be taken during the spawning seasons. All operations tending

to interfere with the growth of young fishes should be done away with. Some of these regulations can on the whole only be effected by international cooperation.

It is estimated that the annual value of fishes and their products mounts up to the great sum of a billion dollars. The most important world fisheries are for herring, salmon (Fig. 227), cod, haddock, hake, pollock, mackerel, and tunas. Next to agricultural products, fish constitute the most important food for mankind. In 1921 the United States exported about $16,000,000 worth of fish and imported

FIG. 227.—ONCORHYNCUS, THE SALMON.

(U. S. Bur. Fisheries.)

nearly $30,000,000 worth. Fishery products are preserved by refrigeration and cold storage; by salting, by smoking, drying, and canning. Among the by-products are oils from the entire fish and used in making soap and in paints, and oils from livers used in medicines. The nutritive and medical properties of cod-liver oil are due in part to the presence of vitamins. If this oil is prepared by heating the liver in the presence of air the vitamins are destroyed. Nor should the oil be bleached with oxidizing or reducing agents, if its valuable properties are to be retained. Liver oils are also used in tanning of leathers. Soil fertilizers are made from fish scrap and fish meal is used as food for stock. Glue is made from fish wastes.

There is also a group of fishes called *Dipnoi* (Fig. 228) (two kinds of breathing apparatus). They are large, fresh-water, mud-dwelling forms. They breathe by means of gills and also the modified swim bladder acts as a lung. The external nares communicate with the mouth cavity. There is a partly divided auricle, i.e., it has a right and left portion. *Ceratodus* is found in Australia, *Protopterus* in Africa and *Lepidosiren* in South America. Although they are physiologically intermediate between fishes and amphibia, yet they are highly specialized and are not to be regarded as the ancestors of the Amphibia. They can live out of water to a certain extent and at that time the air-bladder functions as a lung.

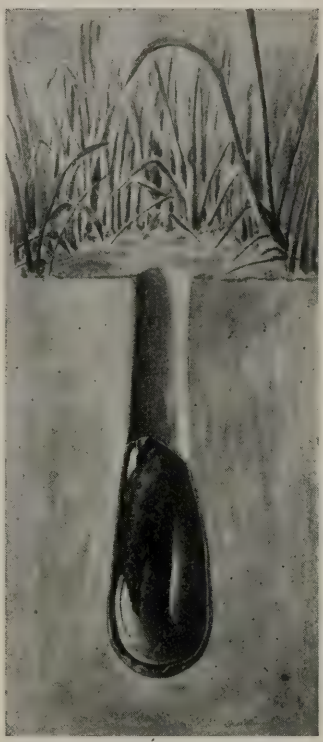

Fig. 228.—Protopterus, African lung fish in its mud nest.

(Amer. Mus. Nat. Hist.)

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CHAPTER XIX

PHYLUM X. SUBPHYLUM II. CLASS IV. AMPHIBIA

General Characteristics.—The Amphibia are Vertebrates which first occupied a land habitat, though still remaining for the most part near water. All are averse to salt water. While they breathe by means of gills during all or part of the life, some of them later breathe mostly by means of lungs. The nostrils open into the mouth and through these nasal passages air for the lungs is taken in. The auricle is divided into the right chamber for general body blood, while the left auricle receives oxygenated blood from the lungs. Paired limbs are present. Their structure is typical for all higher Vertebrates. The differences between paired fins of fishes and limbs of higher Vertebrates are greater than the resemblances. On the other hand, Huxley first noted the great similarities between Fishes and Amphibia and united the two groups, giving them the name *Ichthyopsida*. Some of the differences are:

Fishes:

1. Gills occur throughout life.
2. Swim bladder acts as a lung only in Dipnoi and a few other types.
3. Paired appendages are fins.
4. Heart has two chambers.
5. Usually scales or bony plates.
6. Nostrils do not open into mouth except in Dipnoi.

Amphibia:

1. Gills may be lacking in adults.
2. Lungs appear.
3. Paired appendages are limbs.
4. Heart has three chambers.
5. Skin slimy. Fossil forms and a few modern forms with bony plates on surface of body.
6. Nasal passages from external nares to mouth cavity.

The most commonly known forms of Amphibia are frogs and toads. There are many kinds of these. Following is a general description of a frog of the genus, *Rana*.

External Features.—The body is divided into the head and trunk there being no neck. The head is about as broad

as long, triangular in shape and somewhat depressed horizontally. The wide gaping mouth is in front. At the tip of the snout are the two small external nostrils. The eyes protrude somewhat from the upper lateral region of the head. Behind the eyes are the circular ear drums or tympanic membranes on a level with the surface of the head. The front limbs are short and weak and are used merely to support the front end of the body. The hind limbs are long and powerful. They form the main organs of locomotion. There is no tail. The skin is moist, smooth and loose. In the skin are many glands, secretions of which keep the skin moist. Pigment cells are found in the skin. To a certain extent the frog can "change its spots," due to diffusion or concentration of the pigment in these cells. This action is under the influence of the nervous system.

Muscles.—Underneath the skin are the *skeletal muscles*, that is, those associated with the skeleton in body movements. These muscles are supplied with nerves and in response to a motor nerve impulse give a quick contraction. Muscles are attached to bones by means of tendons which are white inelastic cords of connective tissue. For moving parts of a limb, muscles occur in pairs antagonistic in action. That is, there are *flexors* and *extensors*, *adductors* and *abductors*, *depressors* and *levators*. When one member of a combination contracts, its mate relaxes, and vice versa. Thus orderly movement is possible. This would not be the case if all relaxed or all contracted at the same time. Team work is essential. The frog has many muscles. Careful dissection of the muscles of the hind limb would reveal at least eighteen principal ones. Under the mouth, forming part of its floor is the *submaxillary*. Its contractions raise the floor of the mouth, making the mouth cavity smaller and thus forcing air into the lungs. The *pectoralis* muscles are a pair of large fan-shaped muscles extending from the mid-line of the ventral surface of the pectoral girdle and converging outwards to be inserted into the upper part of the arm on either side. Its contraction moves the front legs. The *rectus abdominis* is a flat muscle on the middle ventral side. On either side of it, forming the ventral and lateral

sides of the trunk, is the *obliquus externis*. The *gastrocnemius* is the muscle of the calf of the leg. It has its origin at the lower end of the femur and is attached by a broad tendon to the ankle. This tendon at its origin from the lower end of the muscle is the *Tendon of Achilles*.

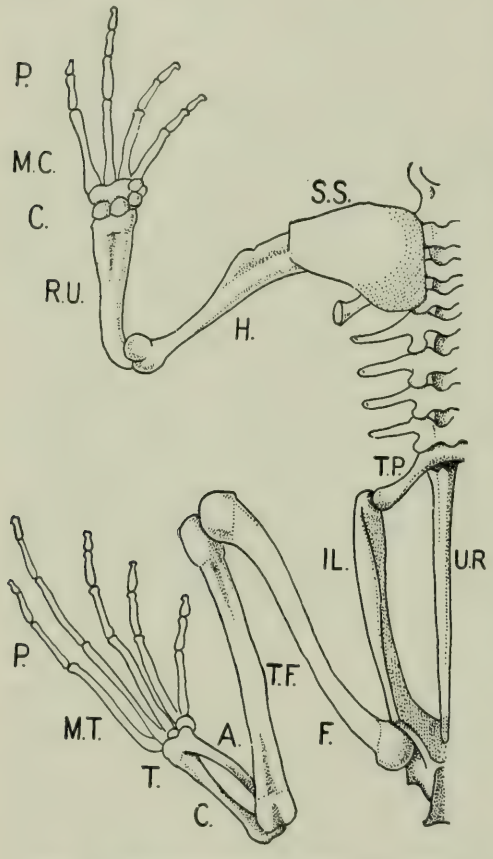

FIG. 229.—PART OF SKELETON OF FROG.

S. S., Supra-scapula; *H.*, Humerus; *R. U.*, Radio-ulna; *C.*, Carpals; *M. C.*, Metacarpals; *P.*, Phalanges; *T. P.*, Transverse process of last vertebra; *U. R.*, Urostyle; *Il.*, Ilium; *F.*, Femur; *T. F.*, Tibia-fibula; *C.*, Calcaneum; *A.*, Astragalus; *T.*, Tarsals; *M. T.*, Metatarsals; *P.*, Phalanges. (After Thomson.)

The frog leaps on land. The front of the body is held off the ground by the fore legs, the trunk and head form an angle with the earth. The hind legs are folded alongside the body. The powerful muscles contract, the hind legs suddenly straighten out, and the body is hurled through the air. In the water frogs oftentimes float beneath the surface with just the tip of the snout exposed and the hind legs hanging down. If surprised they double up or fold the hind legs; the fore legs depress the front end of the body, the hind legs suddenly straighten out and the animals disappear into the depths below. The frog propels itself

in the water by the powerful strokes of the hind legs. The web between the toes and the spreading out of the toes as the legs kick back in swimming help to propel it through the water rapidly.

Skeleton.—Most of the skeleton of the frog is bone. (Fig. 229). The *axial skeleton* consists of the skull and vertebral column. The *appendicular skeleton* consists of the pectoral and pelvic girdles and the bones of the limbs. The *skull* is somewhat flattened and has a number of open spaces (fenestrae) in it. It is composed of a number of bones. The *vertebral column* consists of nine vertebrae and a long posterior bone called the *urostyle*. The *pectoral girdle* and *sternum* form an incomplete arch around the front part of the body. They do not form a bony union with the backbone but are joined to it by tendons, ligaments and muscles. The *pelvic girdle* consists of three pairs of bones. One pair (the *ilia*) have long extensions. The anterior ends of these are immovably fixed to the outer end of the transverse processes of the ninth vertebra. The hinder end of the urostyle rests in a hollow space above the pelvic arch at the junction of its parts. This arrangement makes a strong apparatus well adapted to withstand the strains of leaping. The fore limbs consist of a *humerus*, the *proximal* end of which articulates by a movable junction at a certain point on the shoulder girdle. Outside the humerus is the *radio-ulna*. Then come the *carpals* or wrist bones. Beyond these are the hand bones or *metacarpals* and these terminate in the fingers or *digits*. The first metacarpal bone has no digits, the second and third have two each, the fourth and fifth have three each.

The *hind limbs* begin with the thigh or *femur* bone, the *proximal* end of which forms a ball-and-socket joint with the socket (*acetabulum*) on the side of the pelvic arch. Beyond the *femur* is the *tibia-fibula*. Beyond this are two long ankle bones. At the outer end of these are other small tarsal bones. Then come the five bones of the foot proper, the *metatarsals*. The first and second toes contain two phalanges each, while the third, fourth and fifth have three phalanges each.

Mouth.—There is a large mouth cavity. (Fig. 230.) The flat broad tongue lies on the floor of the mouth and is attached at the front end and free underneath and behind. It is slimy and can be quickly extended, the forked tip curling around and capturing moving insects and worms which are then brought into the mouth. The teeth are small and occur on the upper jaw. Two patches of teeth (*vomerine*) are found on the roof of the mouth. They merely prevent the escape of prey. Externally, on either side of the vomerine teeth are the mouth openings of the nasal passages. In the back of the mouth can be seen the opening of the *oesophagus*. Just in front of this on the floor and between the hinder fork of the tongue is a vertical slit, the *glottis* leading to the lungs. On the outer back part of the roof of the mouth on either side is the mouth opening of the *eustachian tubes* which lead to the middle ear.

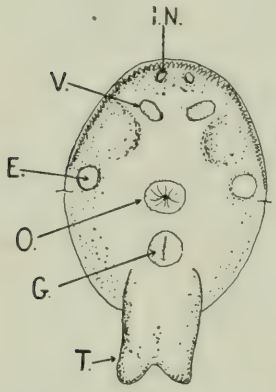

FIG. 230.—MOUTH PARTS OF FROG.

I. N., Internal nares; *V.*, Vomerine teeth; *E.*, Eustachian tube; *O.*, Oesophagus; *G.*, Glottis; *T.*, Tongue.

Digestive System.—The oesophagus passes from the mouth into the abdominal cavity and connects with the *stomach* (Fig. 231) toward the left side of the body. The left end of the stomach is large and saccular, while the right end tapers off into the *duodenum*. The *pyloric valve* is between the stomach and duodenum. The duodenum is the first part of the small intestine. It receives the ducts from the liver and pancreas. The remainder of the *small intestine* is short and leads into the suddenly widening large intestine or *rectum*. This connects with the cloaca which is similar to the cloaca of the dogfish. From the ventral side of the cloaca originates a thin bilobed cloacal (urinary) *bladder*. Urine collects in this from the cloaca. The *liver* is a large, dark red, three-lobed gland covering the stomach and part of the intestine ventrally. The *gall bladder* is on the right

side. From lobular ducts, bile flows into the gall bladder and from this by the common bile duct into the duodenum. The *pancreas* is a filmy white gland between the pyloric end of the stomach and the duodenum. Its secretions pass through the pancreatic duct into the duodenum. Digestion begins in the stomach and continues in the intestine from which the digested food is absorbed into the blood.

Respiratory System.—The skin is plentifully supplied with capillaries capable of absorbing oxygen from the water. The frog's body is always moist and the skin serves as an

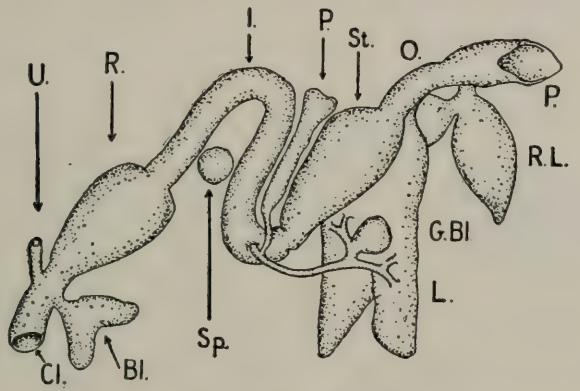

FIG. 231.—DIGESTIVE TRACT OF FROG.

P., Pharynx; *O.*, Oesophagus; *R. L.*, Right lung; *St.*, Stomach; *P.*, Pancreas; *I.*, Intestine; *R.*, Rectum; *U.*, Ureter; *Cl.*, Cloaca; *Bl.*, Bladder; *Sp.*, Spleen; *L.*, Liver; *G. Bl.*, Gall Bladder.

organ of respiration even in air. But the frog also has lungs (Fig. 231). The *glottis* leads into the short windpipe from which originate almost at once the *lungs*. These are delicate sacs which lie on either side of the front end of the body cavity next the liver. The area of the inner surface is increased by the presence of small membranous chambers called *alveoli*. The walls of the lungs are rich in capillaries. The *larynx*, or voice-box, is between the glottis and the lungs. In it are the vocal cords, simply membranous bands stretched across. The edges of these bands are vibrated with air expelled from the lung thus producing the croaking sound.

In breathing, the mouth, oesophagus and glottis openings are closed. The floor of the mouth descends. Air rushes into the mouth through the nasal passages. Then the floor of the mouth is raised, the external nostrils are closed, and the air is forced into the lungs. When the muscles of the body wall contract, the air is forced out of the lungs into the mouth cavity and out through the nasal passages.

Excretory System.—The *kidneys* (Fig. 232) are a pair of dark red bodies about two centimeters long and somewhat less than half a centimeter in diameter, located in the posterior part of the body cavity on the dorsal wall either side of the backbone. Small *ureters*, or urinary ducts, pass from each kidney to the cloaca. On the ventral side of each kidney is a yellow linear shaped body. This is the *adrenal*, a ductless gland. At the anterior end of each kidney is an adipose or fat body. These have yellow, light-colored finger-like processes. It is thought that in these, reserve food supplies are stored to supply the frog with food during the hibernating season. Through the kidneys are excreted primarily the nitrogenous wastes of metabolism.

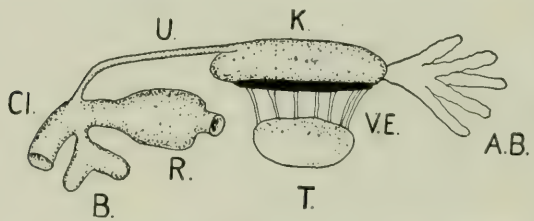

FIG. 232.—URINARY ORGANS AND MALE REPRODUCTIVE ORGANS—FROG.

A. B., Fat bodies. *K.*, Kidney; *U.*, Ureter; *Cl.*, Cloaca: *B.*, Bladder; *R.*, Rectum; *T.*, Testis; *V. E.*, Vasa efferentia: Dark line under kidney is the adrenal gland.

Reproductive System.—The sexes are separate. Sperm are manufactured in the *testes*. These are white bodies about a centimeter long and half as wide, situated underneath, and toward the front end of the kidneys. Each is connected with a kidney by a transparent membrane. In this membrane are very fine ducts, the *vasa efferentia*, through which sperm pass from the testis to the kidney. The sperm then pass through ducts in the kidney to the Wolffian ducts, or ureters, thence to the cloaca. Eggs are

fertilized outside in water. The ureter of the male thus serves as a *vas deferens*, that is, duct for conveyance of sperm.

In the early spring the *ovaries* of the female are enormously enlarged. They have the appearance of great masses of eggs. The eggs are budded off from the ovary into the body cavity. In the body cavity the ripe eggs are passed forward. (Fig. 233.) At the front end of the body cavity they pass into the funnel-shaped anterior ends of the oviducts. The *oviducts* are long, very much coiled tubes which pass on either side back to their entrance into the cloaca. In its passage through the oviduct the eggs receive a coating of gelatinous material. During the day and night eggs continue to pass from the ovary back through the oviduct, collecting in a saccular enlargement, the *uterus*, at the posterior end of the oviduct. Eggs are laid in the early spring. The male clasps the female with his forelegs just behind her forelegs. This is kept up for several days. The eggs which have accumulated in the uterus pass into the cloaca, thence to the water outside. As this occurs the sperm are discharged over them and fertilization takes place. The gelatinous coating of the egg now swells up. The fertilized egg is a cell from which the embryo is to be formed, a mass of yolk to be used in development and the white or albuminous material. This serves to protect the egg during development. Frog eggs with their albuminous coverings are comparable with hen eggs without shells, or shell membranes.

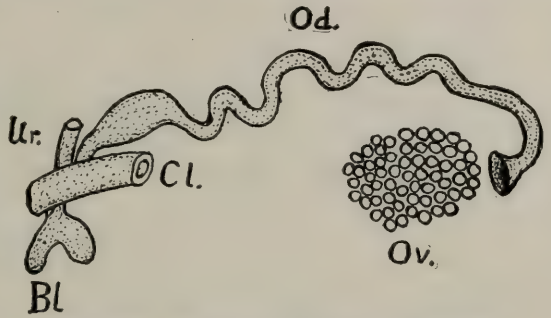

FIG. 233.—FEMALE REPRODUCTIVE ORGANS.
O., Ovary; *Od.*, Oviduct; *Cl.*, Cloaca; *Bl.*, Bladder.

Membranes.—The inside wall of the body cavity is covered with a thin protecting membrane, the peritoneum.

The *viscera* are suspended from the body wall along the backbone by a thin sheet-like membrane, the *mesentery*. In the mesentery and near the stomach somewhat to the left side is a small red body, the *spleen*. This is a ductless gland, with no duct through which its secretions can be discharged. The adrenal, already noted, is another ductless gland. The location and functions of other ductless glands will be discussed elsewhere.

Blood.—The blood of the frog consists of (1) a liquid *plasma* containing food and wastes; (2) white blood corpuscles (*leucocytes*) which are ameboid in form and activity, and

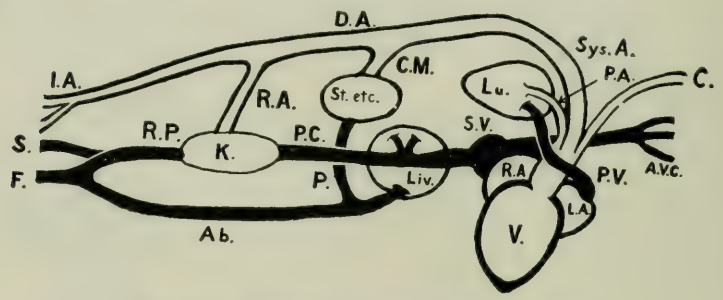

FIG. 234.—SCHEME OF CIRCULATION IN FROG.

Veins in black. *V.*, Ventricle; *C.*, Carotid artery; *Sys.*, *A.*, Systemic artery; *P. A.*, Pulmonary artery; *D. A.*, Dorsal aorta; *I. A.*, Iliac artery; *R. A.*, Renal artery; *C. M.*, Coeliacomesenteric artery; *S.*, Sciatic vein; *F.*, Femoral V.; *R. P.*, Renal portal vein; *K.*, Kidney; *Ab.*, Abdominal V.; *P. C.*, Post caval V.; *P.*, Portal V.; *Liv.*, Liver; *S. V.*, Sinus venosus; *R. A.*, Right Auricle; *L. A.*, Left auricle; *P. V.*, Pulmonary vein; *Lu.*, Lung; *A. V. C.*, Anterior vena cava.

which swallow invading micro-organisms like bacteria and so act as scavengers or policemen of the blood (body); and (3) *red corpuscles* flat, oval-shaped nucleated cells containing *hemoglobin* which has a great affinity for oxygen and by virtue of which the red corpuscles transport oxygen from the lungs and skin to the tissues.

Circulatory System.—The *heart* is triangular in shape. (Fig. 234.) It is located just under the pectoral girdle. Posteriorly is the thick muscular *ventricle*. Anterior to this are the right and left *auricles* which are not so muscular. Between the two auricles on the ventral side is the thick tubular *truncus arteriosus* which arises from the ventricle.

The incoming venous blood empties into a thin-walled sac the *sinus venosus* above the heart. *Arteries* carry blood away from the heart, *veins* carry blood to the heart. Capillaries are a thin-walled network of fine vessels in between arteries and veins and ramify among the various tissues.

The principal arteries are (1) the *carotids*. Each one of this pair arises from a branch of the *truncus arteriosus* and passes forward supplying the brain, eye, tongue, and other parts of the head. (2) the *pulmo-cutaneous*. These also each originate from a branch of the *truncus arteriosus*. The pulmocutaneous soon divides into (*a*) the *pulmonary*, which passes to the lungs, and (*b*) the *cutaneous*, a branch which goes to the skin. They carry blood to the lungs and skin to be oxygenated.

Between the carotids and pulmocutaneous on either side and arising from the branch of the truncus arteriosus is a third artery, the *systemic*. Each systemic passes dorsally and posteriorly around the *alimentary tract*. They unite above the intestine to form the *dorsal aorta*. This passes backwards, giving off large branches to various organs. At the posterior end of the body it divides into the two *iliac arteries*, each of which breaks up into the arteries of the hind leg. Each systemic before it unites with its fellow gives off important branches to the head, backbone, and arm. At the junction of the systemics with the dorsal aorta arises the *coeliaco-mesenteric*, which has important branches to the liver, stomach, pancreas, spleen and intestine. Small branches from the dorsal aorta supply the muscle of the body wall, the ovaries, testes and kidneys.

The blood from the skin and lungs returns through the pulmonary vein to the left auricle. A large *anterior vena cava* vein on either side returns venous blood from the head to the sinus venosus. The single posterior *vena cava* returns blood to the sinus venosus from the liver, from the kidneys and from the ovaries. Certain veins from the hind legs pass into the *renal portals* which carry blood to the kidneys. After removal of nitrogenous wastes this blood passes through the *post cava* to the heart. Other veins from the hind legs unite to form the *abdominal* vein. This vein runs

forward along the mid-ventral line of the abdominal wall and passes into the liver whence the blood is returned to the heart via the post cava. Blood from the stomach, intestine, spleen and pancreas passes into the *portal vein*, which passes forward to the *abdominal* and thence to the liver. The portal vein thus conveys absorbed food material and secretions into the general circulation. This is called the *hepatic portal system.* Blood from the liver passes into the post cava through the hepatic vein.

From the sinus venosus the blood passes into the *right auricle.* The blood from the lungs fills the *left auricle* at the same time. Both auricles contract and both bloods are discharged into the ventricle, filling it. When the ventricle contracts, valves between the ventricle and auricles prevent the blood from returning to the auricles. The blood is forced into the *truncus arteriosus*, into its two branches and into the *carotid*, *pulmocutaneous* and *systemic* arteries. Valves and sub-divisions in the truncus arteriosus separate the blood somewhat. The impure blood from the veins passes out chiefly to the *pulmocutaneous arteries* for oxygenation. Blood which just came from the lungs and skin passes through the carotid arteries to the head and brain, which of all organs needs oxygenated blood most. The systemic arteries probably receive a mixture of venous and oxygenated blood.

Large *lymph spaces* are found in the frog. Lymph spaces are found under the skin of the back, two over the third vertebrae and two over the end of the backbone. They pulsate and force the colorless lymph which contains white blood cells, but no red blood cells, into the veins.

Nervous System.—The nervous system is divided into three regions. (Fig. 235.) (1) The *central nervous system* composed of brain and spinal cord; (2) *peripheral*, composed of nerves from the central nervous system; (3) *sympathetic system.*

The brain possesses two large *olfactory lobes.* Behind these is the *cerebrum*, composed of two *cerebral hemispheres.* Next comes the small *between-brain* or *diencephalon*, which has the *pineal gland* above and the *pituitary gland* (ductless) below; behind this are the *optic lobes* and behind these the

small transverse *cerebellum*. Between this and the *spinal cord* is the triangular *medulla* with the fourth ventricle on the dorsal side. The frog has ten pairs of *cranial nerves*. Of these the first pair are the *olfactory*, which carry sensory impulses of smell to the brain, the second or *optics* carry sensory impulses of vision to the brain, the eighth or *auditory* carry sensory impulses from the ear (auditory and equilibrium) to the brain. The third pair, *oculomotor*, the fourth, *trochlearis*, and the sixth, *abducens*, all carry motor impulses from the brain to muscles of the eye.

The fifth, *trigeminal*, is a large nerve which contains both sensory and motor-fibers, but chiefly sensory from skin of face, mouth, and tongue.

The seventh is the *facial*, also a large compound nerve, but carries chiefly motor impulses to the muscles of the face. The ninth is the *glossopharyngeal* and the tenth is the *vagus*, both compound nerves. The ninth innervates the pharynx and tongue, the tenth is interesting and so called because it leaves the head and "wanders" back into the body, supplying lungs, heart, stomach and intestine. Similar cranial nerves are found in all Vertebrates. Higher Vertebrates have two more.

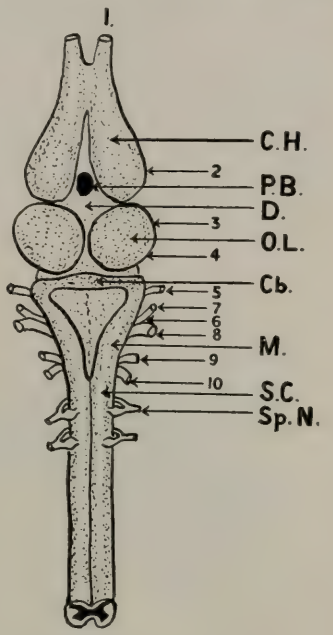

FIG. 235.—DIAGRAM OF PART OF NERVOUS SYSTEM OF FROG.

C. H., Cerebral hemispheres; *P. B.*, Pineal body; *D.*, Diencephalon; *O. L.*, Optic lobes; *Cb.*, Cerebellum; *M.*, Medulla; *S. C.*, Spinal cord. 1, Olfactory tract; 2, Optic nerve (underneath); 3, Oculomotor; 4, Trochlear and 6, Abducens nerves underneath; 5, Trigeminal; 7, Facial; 8, Auditory; 9, Glossopharyngeal; 10, Vagus nerves. *Sp. N.*, Spinal nerve root. (From Ziegler Model.)

There are ten pairs of spinal nerves arising from the spinal cord, which is enclosed in the bony arch above the bodies of the vertebrae. Each spinal nerve originates from the cord

by two roots, a *dorsal root*, which carries sensory impulses into the cord from the periphery, and a *ventral root* which carries motor impulses out of the cord to body muscles. The two roots unite outside the cord to form the *spinal nerve*, some of whose fibers originate in sensory organs of the body and other fibers which terminate in motor end-plates in muscles. The largest spinal nerves are the *brachials*, which run to the arms, and *sciatics*, which supply the legs. In each of these cases more than one pair of spinal nerves cooperate to form the nerves of the legs.

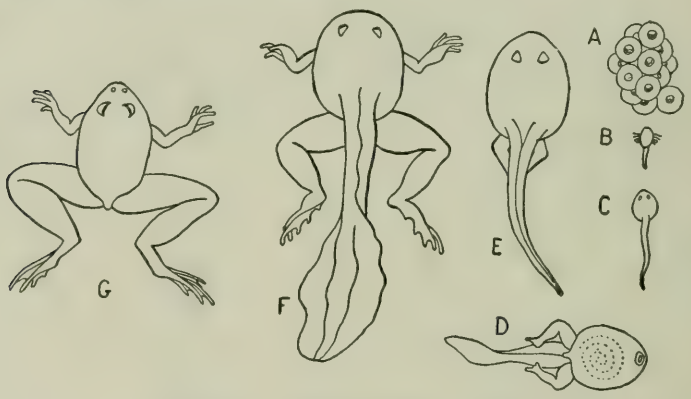

FIG. 236.—DEVELOPMENT OF FROG.

A, Egg mass; *B* and *C*, Young tadpoles; *D*, Under side of young tadpole with coiled intestine; in *D* and *E*, hind legs appear; in *F*, front legs also; in *G*, tail absorbed. (From Paulmier, N. Y. State Museum.)

The *sympathetic system* is collateral to the *central system*. It possesses two main thread-like trunks, one on either side of the backbone. Each sympathetic trunk is connected to a spinal nerve ganglion occurring at each junction. Nerves from the sympathetic system are distributed to the heart, liver, lungs, kidneys, head, alimentary tract and other internal organs.

Sense Organs.—The frog possesses nose, eyes, ears and other sense organs. There is no *outer ear*. The *middle ear* is a chamber beneath the *tympanic membrane* and the *inner ear* is enclosed in bone and contains the sensory cells of hearing. Sound waves are communicated from the ear drum

to a membrane in the outer wall of the inner ear by a rod, the *columella*. Fishes have not even a *middle* ear.

Development.—From the developing egg of the frog hatches a tadpole. This is a fish-like form. (Fig. 236.) It has gills, and swims by means of a long tail. It feeds mostly on vegetable matter. Two sets of gills are formed. First, external gills which project out from the sides of the head. These are replaced by internal gills more like those of fishes. Hind limbs appear as buds and gradually increase in size and perfection. The front limbs appear later and are first formed inside of a temporary sac called the *operculum*.

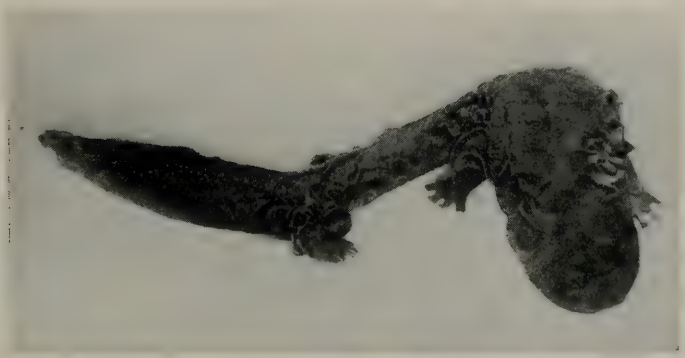

FIG. 237.—CRYPTOBRANCHUS—THE HELLBENDER.

(Amer. Mus. Nat. Hist.)

This operculum encloses a sort of atrial chamber about the sides and floor of the mouth. Water taken into the mouth passes out through the gill slits into the atrial chamber and from this to the outside. The front limbs poke their way through the operculum. The tail is gradually absorbed and lungs appear. With the development of these, the circulatory system develops new arrangements also. It changes from a fish-like type to the adult frog type. With the assumption of land existence the frog moves about and breathes like a land animal. The changes connected with the transition from the aquatic fish-like form to that of a land-inhabiting frog are called *metamorphosis*.

Classification.—There are about a thousand kinds of Amphibians. They form a transitional group between the Fishes and land Vertebrates. The name of the group signifies that they live in the water and on land.

Order 1. Apoda or Gymnophiona.—A few species are limbless and snake-like in form. These are called *Coecilians.* They are tropical burrowing animals with poorly developed eyes. The tail is very short and there are transverse rows of plates in the skin.

Order 2. Caudata or Urodela.—In these the tail persists throughout life. The external gills and gill clefts may also persist throughout life. The limbs are small and weak.

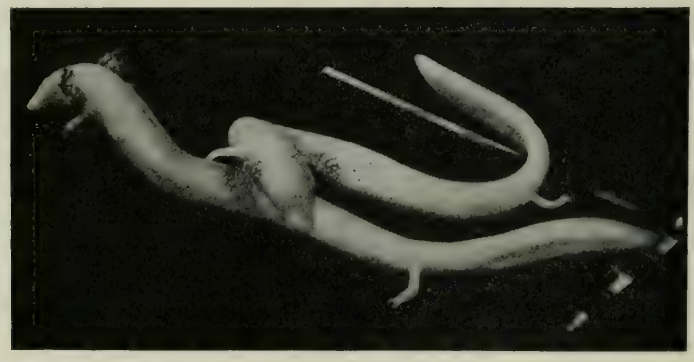

FIG. 238.—AMPHIUMA, THE CONGO EEL.

(Amer. Mus. Nat. Hist.)

Cryptobranchus maximus is the largest living amphibian. It is found in Japan and may grow to be over three feet in length. *Cryptobranchus alleghaniensis* (Fig. 237) is the hellbender found in streams in the eastern part of the United States. It attains a length of about eighteen inches. The Congo eel (Fig. 238), *Amphiuma means,* is eel shaped and has two pair of small limbs far apart. *Triturus viridescens,* a newt, is about three inches long and has a row of red spots along each side of the body. *Amblystoma tigrinum* (Fig. 239) about six inches long retains its gills and also breeds in the larval form if metamorphosis is prevented. Such larval forms of *Amblystoma* were thought to be a separate

species. It was called the *Axolotl*. *Desmognathus fusca* lives in dark moist places. It has no lungs or gills. Two

FIG. 239.—AMBLYSTOMA TIGRINUM, TIGER SALAMANDER.

(Amer. Mus. Nat. Hist.)

long strings of eggs are laid by the female who winds them about her body and remains with them until the young hatch.

Order 3. The Salientia or *Anura*.—These are the frogs and toads and include about nine hundred species. They have no tail nor do the adults possess gills. *Bufo*, the toad, has a warty skin. The secretions of the skin glands of some tropical species are very poisonous. Common toads (Fig. 240) destroy garden insects in great numbers and so are valuable aids to agriculture. Toads breed in the water. Eggs are laid in strings. Development from egg to adult condition takes but a few weeks. At the end of

FIG. 240.—BUFO, COMMON TOAD.

(Amer. Mus. Nat. Hist.)

this time very small toads leave the water. Tree frogs have sucker-like pads on their digits enabling them to live in trees. The female of the Surinam toad (Fig. 241) transfers the fertilized eggs to a soft spongy tissue on her back. Here the toads develop. *Nototrema,* a tree frog of Venezuela has a brood pouch on the back in which the eggs

FIG. 241.—PIPA AMERICANA—SURINAM TOAD.

(Amer. Mus. Nat. Hist.)

develop. The bullfrog, *Rana catesbiana,* is a very large species of frog. It is frequently eight inches in length. *Alytes obstetricans* is so called because the male winds the eggs about his hind legs and keeps them there until it is time for them to hatch when he moves to the water so they can be free. Salamanders can regenerate limbs they have

lost. Tadpoles of Anurans can do this also but the adults cannot. Most Amphibia are oviparous. Amphibia hibernate in the mud during the winter. Physiological activities are then at a low ebb.

Fossil Amphibians.—*Stegocephalia* were large Amphibia existing in prehistoric times. Skeletal remains have been found from the Carboniferous through the Triassic geological periods. They had large bony plates on the surface of the skull and in other parts of the body. We have no knowledge of any earlier forms possessing the typical land type of limb. Modern Amphibia appear in the Tertiary. It is thought by some that they were derived from a fish-like form related to the Dipnoans. They also show similarities to the Reptiles above them.

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CHAPTER XX

PHYLUM X. SUB PHYLUM II. CLASSES V AND VI. REPTILIA AND AVES

Class V. Reptilia

General Characteristics.—Reptiles, like the lower forms, are cold-blooded, i.e., the body temperature is about the same as that of the air outside. The body is covered with epidermal scales, the toes (if these are present) have claws; the gills are only embryonic structures, they breathe by means of lungs. Embryonic respiration is carried on by a foetal sac called the *allantois*. The foetus is protected by a fold called the *amnion*. Reptiles, Birds, and Mammals are alike in a number of respects and so are called *Amniota* to distinguish them from Fishes and Amphibia known as *Anamniota*. Reptiles and Birds have been termed *Sauropsida* in distinction from the *Ichthyopsida* (Fishes and Amphibia). They are oviparous for the most part, laying eggs which have yolk, white (albumen), membranes and shells. Development usually occurs outside the body. The development of reptiles and birds especially during early stages is very similar. Fertilization of eggs is internal, i.e., sperm pass from male to female during copulation. The circulatory system of Reptiles in many respects is similar to that of Amphibia—the urinary system is embryologically a new system as will be shown later.

Classification

There are four principal groups of Reptiles living to-day.

Order I. Lacertilia or Lizards.—They have horny scales which are shed periodically. Most have two pairs of legs and a long tail. The bones of the skull are immov-

able. The species are most numerous in warm countries. The largest lizards are the Monitors. *Varanus* of the Nile may grow to be six feet in length. The *Iguana tuberculata* (Fig. 242) of tropical America grows as large. The horned toads of the hot dry lands of the Southwest are not toads but lizards. *Heloderma suspectum*, the Gila monster (Fig. 243) of Arizona and New Mexico, is a large stout bright-colored lizard that is said to be poisonous.

FIG. 242.—IGUANA TUBERCULATA—THE IGUANA.

(Amer. Mus. Nat. Hist.)

Order II. Ophidia.—These are snakes or serpents. Their body is covered with scales. They have no limbs or limb girdles except vestiges of them in Boas. On the ventral mid-line anterior to the anus is a row of large scales to the inner end of which the outer ends of the ribs are attached. The outer edges of these scales act as fulcra of levers moved by the muscles of the body wall. The scales, ribs and muscles form the organs of locomotion. The absence of limbs and sinuous nature of the backbone enables serpents to crawl into small crevices and through labyrinthine passages. They can swim also. There is no ear-drum and the sense of hearing is poor. The tongue is forked and is pro-

trusible. It probably reacts to other than taste stimuli. Teeth are sharp and pointed backwards. They assist in holding the prey and in swallowing. In poisonous forms, they are grooved or have canals through which the poison from the poison glands runs down into the tissues of their victims. The poisoning operation is similar to the action of a hypodermic syringe. Many of the bones of the skull are movable—the jaws can be expanded. In this way the snake can swallow what seem to be very large animals in

FIG. 243.—HELODERMA, THE GILA MONSTER, WITH EGG.

(Amer. Mus. Nat. Hist.)

comparison to the size of the head. The backbone has many vertebrae—in some pythons there are as many as four hundred. Poisonous snakes have fewer teeth than harmless forms. Most snakes lay eggs, and are more common in warm countries.

The boas and pythons live on birds and mammals. They kill their prey by crushing them. The regal python of Burma may grow to be thirty feet in length. The garter snake, water snake, black snake are examples of common harmless snakes of this country. The king snake boldly attacks venomous snakes. The hog-nosed snake when surprised puffs up its neck—hisses, acts vicious—then falls

limply, feigning death. When it is assured that the coast is clear, it carefully moves off.

Real sea serpents live in the Indian Ocean and tropical parts of the Pacific. They may grow as large as eight feet long and most species are very poisonous. The coral snake, *Elaps fulvius*, of South Eastern United States is very poisonous. The back of the body is marked with scarlet and blue-black cross bands, separated by narrow bands of yellow. The water moccasin, *Ancistrodon piscivorus*, is found in swamps of the South. It is poisonous. *Ancistrodon contortix*, the copperhead, has a habitat extending further North. It is also poisonous and never makes known its presence. The rattlesnake, *Crotalus* (Fig. 244), also poisonous, has a rattle at the tip of its tail. This is a number of horn-like segments loosely arranged, which vibrate when the snake is excited. The great diamond-back rattler of Florida swamps (Southeast U. S.) may attain a length of eight feet, and the great size is an index of its venomous nature.

FIG. 244.—CROTALUS, RATTLE SNAKE.
(New York Zool. Soc.)

The cobra, *Naja* (Fig. 245), China and Malay archipelago, is vicious and deadly. In India thousands of natives are killed by this serpent. The mongoos, a Mammal (*Herpestes grissus*), is the deadly enemy of the cobra. The mongoos is fearless, extremely rapid in its movements and very cunning. Cobras from which the fangs have been removed are used by Indian snake charmers. The king cobra or *Hamadryad* is the largest of poisonous snakes, sometimes being fourteen feet long. Gadow says its size and poisonous nature make it the curse of the jungle. It can

easily outrace a man in the jungle and will attack one. The *Krait* causes more deaths in India than any other snake because it is so numerous and creeps into houses after rats. The development of anti-venom sera treatments is saving many lives from death by snake poisons to-day. The treatment for snake poisoning is not general, but a special anti-venom must be used for each kind of venom. Some snake poisons destroy red blood cells.

Most of our common harmless snakes are of real value

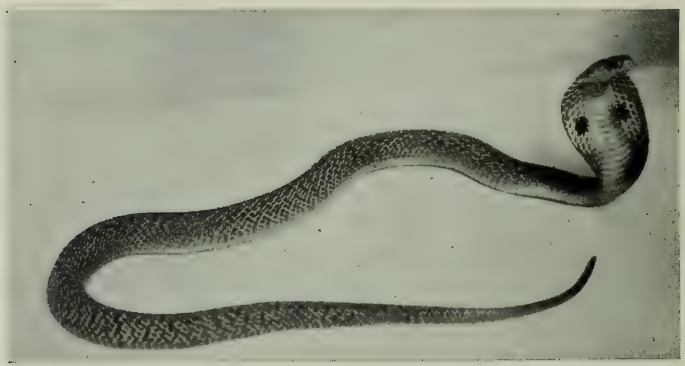

FIG. 245.—NAJA—THE COBRA.

(New York Zool. Soc.)

to the farmer since they destroy rats, mice and many injurious insects.

Order III. Chelonia.—These are the land-inhabiting tortoises and the water-inhabiting turtles and terrapins. They have an exoskeleton of horny epidermal shell which covers a deeper dermal layer of bony plates. The soft parts are enclosed in this "box," the upper part being called the *carapace* and lower part the *plastron*. The vertebrae are immovable, with the exception of those of the neck and tail. The limbs protrude between the carapace and plastron. There are no teeth, but the edges of the jaws have sharp ridges. They deposit eggs in sand or earth where they are left to develop. Some eat animals, others feed on plants. The diamond-back terrapin (Fig. 246) is highly prized as

food. On account of their increasing scarcity and the great demand for them because of the flavor of their meat, the U. S. Bureau of Fisheries has conducted successful experiments in propagating them. The plastron of the box tortoise is hinged so that in danger the animal draws in its head and tail and the shell closes down completely. The giant tortoises *Testudo abingdoni* (Fig. 247), are large tropical forms and living representatives of ancient forms. They too are becoming extinct.

The green turtle, *Chelonia midas*, ranks next to the diamond-back terrapin as an article of food. The horny

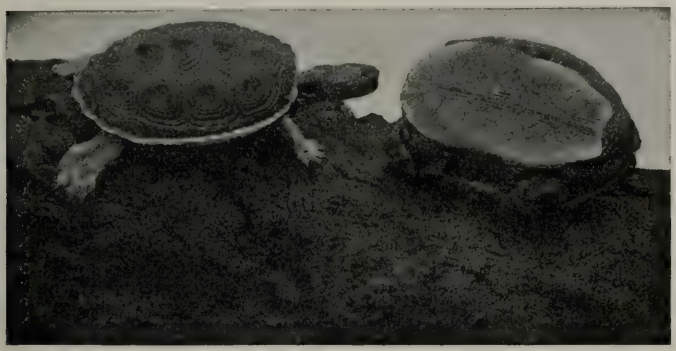

FIG. 246.—MALACOCLEMMYS, DIAMOND-BACK TERRAPIN.

(Amer. Mus. Nat. Hist.)

carapace of the hawk's-bill turtle, *Chelonia imbricata*, resembles tiles on a roof. This is the source of the tortoise shell used in making combs and ornaments. Tortoise shell was one of the treasures brought to Rome from the Far East by caravan through Egypt. The development of synthetic substitutes for horn-like materials has rendered the using of real tortoise shell unnecessary. The leathery turtle, *Sphargis* (Fig. 248), found along the coast of Florida and Brazil, is the largest of the turtles. Specimens have been found that were eight feet long and weighed over 1600 pounds. Its flesh is unfit for food, however.

Order IV. Crocodilia.—These are large reptiles, lizard-like in form. The jaws are extended into a long snout.

The nostrils are at the tip of the snout. The eyes are raised from the head and are some distance behind the nostrils, so that the animal often remains at the surface with the body just submerged and only the eyes and nostrils above the water. It is thus concealed and in a good position to watch for its prey. The skin is leathery and covered with epidermal scales. Underneath the body are bony plates. Crocodilia are carnivorous and most of them

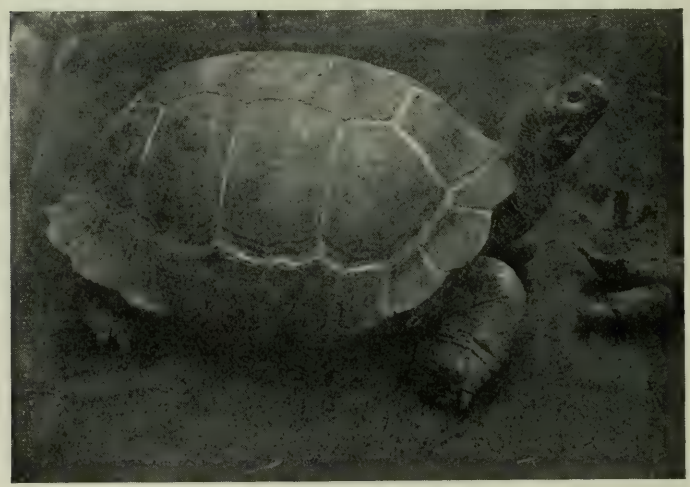

FIG. 247.—TESTUDO, GIANT TORTOISE.

(Amer. Mus. Nat. Hist.)

live in fresh water. The jaws are provided with a marginal row of conical teeth. Other reptiles have a three-chambered heart although there is an incomplete ventricular partition. In the Crocodilia this is almost complete so that the heart has a right and left ventricle as well as a right and left auricle. Moreover the lungs are separated from the viscera by a sort of diaphragm, as in mammals, and this aids in respiration. Crocodilia are most active in water. They swim with powerful strokes. On land they move with difficulty. The larger forms lie in wait near the shore for large mammals—pigs and even human beings. They grasp their

prey in their strong jaws and draw it under the water to drown it. It is allowed to decay until it gets soft enough to eat. The brain is very small. The eggs are larger than hens' eggs and are laid in hollowed-out depressions where they hatch, warmed by the sun's heat. On the whole Crocodilia are sluggish animals basking motionless in the mud under the

FIG. 248.—SPHARGIS, LEATHERY TURTLE.

(Amer. Mus. Nat. Hist.)

hot sun for hours at a time. The limit of growth is more indefinite than for most animals. A little bird, *Pluvianus egypticus*, lives in friendly relationship with the Indian crocodile, feeding on its body parasites. Herodotus makes the assertion that this bird cleans the teeth of the crocodile.

There are three groups of Crocodilia: 1st, *True Crocodiles;* 2d, *Alligators;* 3d, *Gavials.* The Crocodiles are

found in Africa, Southern Asia, tropical Australia, Central America, and West Indies. One species is found in Florida. The Alligators live in southeastern United States and in China. The Gavials live in India, Borneo and Sumatra. They have long slender snouts. The Indian gavial is commonly twenty feet long. The Alligator (Fig. 249) has a broad blunt snout and shorter head than the crocodiles. Its body is stouter and the animals are not so active. The average length is twelve feet. The largest American crocodile is *Caiman niger*, found in the Upper Amazon. Individ-

Fig. 249.—Alligator mississipiensis.

uals twenty feet long have been found. Skins of Alligators make a good and handsome leather.

Relations.—The Reptiles were once the dominant group of Vertebrates. A further account of this is given in the chapter on Palaeontology.

Class VI. Aves

General Characteristics.—A *Bird* (Fig. 250) is a feathered Vertebrate. Birds and Mammals are the most highly organized Vertebrates. Reptiles were the ancestors of both. They are highly differentiated, although along different lines. Birds successfully and easily navigate the air. They are warm blooded and the blood has a constant temperature, somewhat over 100° F. The fore-

limbs are wings (Fig. 251) and the bones of the wrist and hand are reduced in number or size to form this organ. A broad surface which combines the functions of both propellers and planes of the aeroplane is the result. The *pectoral muscles* are enormously enlarged for the operation of the wings and the breast bone is increased in size to afford a large surface area for the attachment of these muscles. The long tail of other Vertebrates is represented in birds by a few vertebrae which form a short stump. There is a movable neck. Birds are bipedal and the structure of the hind limbs is modified to produce limbs which can function in this way. The toes are modified for various habits also. The bones of the brain case fuse so that there are no indications of the component parts. Many of the bones of the skeleton possess air spaces. Air sacs are also present in the body. These are all indirectly connected with the lungs. This condition is related in some way to the aerial habits of these vertebrates. There are no teeth in the jaws, which instead are cased in horn. The *saccular crop*, in which food is softened, is connected with the oesophagus. From the crop the food passes to a glandular portion of the stomach where gastric juice is poured into the food. Behind this is the thick

FIG. 250.—OREORTYX PICTUS, CALIFORNIA QUAIL.

muscular *gizzard* whose contractions, aided by small pebbles inside, act like a mortar and pestle or mill in grinding the food into a mass of fine particles. Behind the gizzard is the small intestine. The large intestine is short and leads into a cloaca as in the lower Vertebrates. A large liver, a pancreas, a spleen and ductless glands are present as in the lower groups. The blood contains plasma, white corpuscles, and oval nucleated red corpuscles. There are two separated auricles and two ventricles. The venous blood of the body enters the right auricle, thence into right ventricle, thence to the lung, thence to left auricle, thence to left ventricle, thence to the body via the aorta.

FIG. 251.—SKELETON OF COMMON FOWL, GALLUS.

(Photo by Author.)

The aorta of birds is homologous with the right systemic arch of Amphibia and Reptiles and the right branch of the second branchial arch of fishes. There is a long windpipe. At the junction of the windpipe with the bronchi of the lungs is the *syrinx*, a special voice-box found in birds. It has *vocal cords* and here the songs of birds are produced. The lungs are composed of multitudes of fine *alveoli*. This is also true of the Mammalian lung. The reptile lung does not possess so many of these, but contains large spaces. Connected with the lungs is a system of air sacs or bladders, and also the hollow spaces in the bones. The cavities of the breast and abdomen expand, when air fills the lungs.

When the muscles of the chest and abdomen contract air is driven out of the lungs. Air in a bird's lung is probably more completely renewed by each respiratory act than in the lung of a Mammal. The mechanism for the supply of oxygen must be of a high order for rapid flight. The bird seems to be well equipped in this regard. Few other animals can maintain such a sustained persistence of active movement as birds. For example, Beebe describes gulls which kept pace unceasingly with a ship for over seven hundred miles from New York to Florida, for about four days and four nights. It is probable, however, that during a considerable part of this time the gulls *planed* along, carried by air currents.

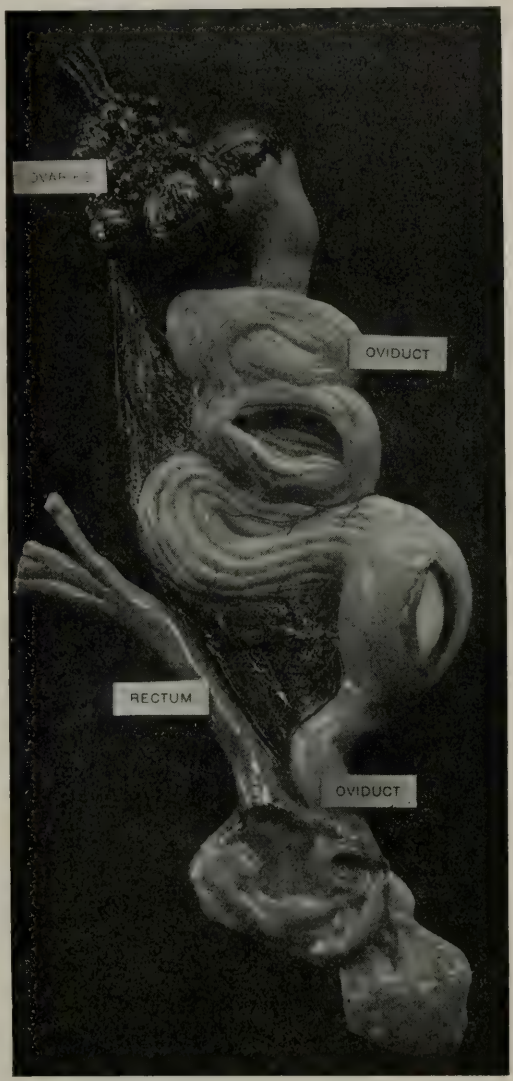

FIG. 252.—REPRODUCTIVE ORGANS OF HEN.
(Amer. Mus. Nat. Hist.)

There is no urinary bladder in birds. The urine is

semi-solid. Probably water is excreted with expirations. The right ovary and right oviduct usually degenerate (Fig. 252). This is correlated with the large size of the eggs. There is usually no organ of copulation but nevertheless copulation takes place and fertilization is internal. Eggs of Birds and Reptiles are quite similar. The hen's egg (Fig. 253) hatches in about twenty-one days and the pigeon's egg in fourteen days. During this incubation period the eggs are kept at a temperature of about 100° F. by the warm body of the female bird as a rule, although in some cases the male and female alternately incubate the eggs.

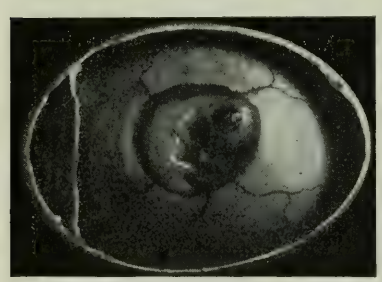

FIG. 253.—TEN-DAY OLD CHICK EMBRYO.

(Amer. Mus. Nat. Hist.)

After hatching, the young birds are soon able to forage for themselves. The brain fills the cranial cavity. There are relatively *large* smooth cerebral hemispheres. The olfactory lobes are small. Birds do not possess a highly developed sense of smell. The optic lobes are large and are behind the cerebrum and lateral to the cerebellum. This has a large median and transversely ridged part and two smaller lateral regions. The embryo brain is more reptilian in form. The sense of hearing is highly developed, and the sense of sight still more so.

Birds are exceptionally uniform in general structure. The differences are in details. On this account it is almost impossible to satisfactorily subdivide the group into a series of distinct types.

The Class Aves is divided into two groups: *A. Archaeornithes,* and *B. Neornithes.*

Archaeornithes.—These are represented by a single type called *Archeopteryx lithographica.* Two fossil specimens have been found in Solenhofen lithographic stone in Bavaria. The Archaeopteryx was about the size of a crow. Its body was covered with feathers as in modern birds. It had small

uniform teeth in both jaws. There were twenty-three vertebrae in the tail and each vertebra possessed a laterally placed feather on each side extending outward horizontally. The ends of the three digits (Nos. 2, 3, 4) were clawed. It probably used all four limbs in climbing trees. Its structure indicates that it is intermediate between reptiles and modern birds. The Archaeopteryx lived in the Mesozoic era.

Neornithes.—These are the modern birds. There is a short tail with but few vertebrae, around which the tail feathers are arranged in a semicircle or fan. A few extinct forms had teeth though no modern birds have them. There are two groups of the Neornithes:

FIG. 254.—SKELETON OF OSTRICH.
(Photo by Author.)

Division I. Ratitae.—These are large birds in which the wings degenerated to a small size or are even absent. As a consequence, the wing muscles are small and weak while the sternum has no keel. The hind limbs are large and very strong. These forms walk or run over the land. Ostriches are (Fig. 254) found in Africa or Southwestern Asia and South America. They live in desert regions and are usually gregarious. They can attain a speed of sixty miles an hour. Ostriches are now successfully reared on farms at a number of places in this country. They have a formidable weapon in a large horny toe and powerful hind legs. The cassowary (*Casuarius*) and emu (*Dromaeus*) are found in Australia and the kiwi (*Apteryx*) in New Zealand. The Moa (*Dinornis*), a very large wingless bird, has become

extinct within the last five hundred years. They occurred in New Zealand and some of them were ten feet high. They had enormous hind limbs.

Division II. Carinatae.—The Carinatae are birds with a well-developed keel on the breast bone. To this are attached the large muscles used in flying. The birds with which we are most familiar, sparrow, robin, bluebird, eagle, belong to this group. The common mode of flight is by the movement of the wings forcibly downward and forward, followed by an upward and backward movement, then again a downward and forward movement. They glide by holding the wings outspread and tilted at an angle, as is usual in gliding from an eminence to the ground. They sail or soar aloft with outstretched motionless wings in the wind. A few species are distinctly songbirds. The song is characteristic of the species. It apparently expresses emotional feeling and is more highly developed during the breeding season. Some, as the parrot, can be taught to pronounce words. Some carnivorous birds live alone except during the breeding season. Some live in pairs as the doves, many live in groups. Fowls are polygamous. Many birds exhibit the phenomenon of courtship prior to or during the mating season. The males are often highly colored and plumed while the females are plain and drab. Darwin thought that this highly decorative condition of the male was produced by a sort of selection. He thought that the female selected the " handsomest " male and that generations of this so-called Sexual Selection produced the marked differences between the sexes or *sexual dimorphism.* It can not be said that this theory has been proven. Most birds build nests. Each species has its own kind of nest and builds it of special materials. Some nests are quite wonderful structures.

The size of the egg is somewhat related to the size of the bird. The egg of the extinct *Æpyornis* was about 150 times as large as a hen's egg. That of the Moa was about nine inches in diameter and twelve inches long. The markings on the egg are characteristic of the species. The colors often blend in with the background. Some of the newly

hatched young are naked, blind and helpless, as is the case with most songbirds. The chicks of the common fowl run around and feed themselves a few hours after birth.

Usually after the breeding season birds lose their old feathers and new feathers replace the old. Sometimes this moulting occurs rapidly, so that the bird (duck or goose) cannot fly for a time. Some birds moult more than once a year. The ptarmigan moults three times a year. After

Fig. 255.—Ptarmigan in winter.

(Amer. Mus. Nat. Hist.)

the breeding season it becomes gray, in winter (Fig. 255) the bird is white and in spring as the mating season approaches it changes for a third time to a mottled brown. The food is of all kinds. Some birds with long intestines are herbivorous, eating green parts of plants; others eat grains. In these birds crops and gizzards are highly developed. Some eat grains and insects. Humming birds sip the nectar of flowers. Some feed on insects and fruits. Some on worms and fishes. In these the *proventriculus* (glandular

stomach) is more highly developed than the gizzard. Red pepper in the food of the canary bird changes its plumage.

The migration of birds is not altogether understood (Fig. 256). It is a remarkable phenomenon. There are many birds that migrate. The golden plover is probably the greatest wanderer of all. In June it is found above the Arctic circle. In August in Labrador—then to Nova Scotia thence to Brazil and Argentine. Thomson says that " the dotterel may sup on the North African steppe and breakfast next morning on the Arctic tundra." For centuries it has easily paralleled what we term as remarkable, the recent trans-continental flight by airplane from New York to San

FIG. 256.—CANADA GEESE IN NEW YORK.

(Photo by Fread.)

Francisco during the hours of daylight. In temperate regions some birds arrive from the South in the spring and return South in the autumn. Other birds arrive from the North in the fall and return North in the spring. Some appear each spring and fall, stopping for a short time on their way north and south. It is a matter of surprise that notwithstanding the variations in the weather from year to year, that the migrating birds appear at just about the same time. Some individuals come back to the same nest. They travel at night even over the seas, and in some mysterious way arrive at a very particular destination. There is little doubt but that food and temperature and problems of rearing the young are important factors concerned in migra-

tion. But they do not wholly explain it. Migration is a deep-laid instinct.

It seems that birds have a highly developed " sense of direction " as one has put it. Flying at night, over miles of sea and over miles of land, they are not lost or confused. Beebe tells us that certain land birds blown out to sea in a storm landed on shipboard and there remained during the storm over night. Early the next morning they left, headed toward the land over fifty miles away and not at all visible from the ship. As another good illustration of the sense of direction of birds there is the well-known example of the homing or carrier pigeons. So far there has been no satisfactory explanation of what this " sense of direction " really is.

Wings.—The feet, wings, and bills of birds vary adaptively in many directions. The ostrich, a flightless bird, possesses only a trace of wings. Penguins have wings but cannot fly. These wings are used as paddles in swimming. The legs act as rudders. Gulls and albatrosses have long pointed wings. The wandering albatross has a wing spread of twelve or fourteen feet. The young hoatzin of South America has claws on the thumb and first finger of the wing. Long before they fly they clamber up trees with the aid of both the clawed wings and feet. The man-o'-war bird has a body about as large as a chicken but a wing spread of eight feet and a tail eighteen inches long. The shape of the tail is governed by the type of flight. The tail acts as a rudder in flight and a balancing organ when perching. Short-tailed birds fly in a straight course. The tail of some male birds, such as the lyre bird and pheasant, is an organ of beauty. Its gorgeous character seems to be consciously displayed by the turkey and peacock. (Fig. 257.)

Feet.—There is a correlation between wings and feet. Short-winged ground birds, like quails, have well-developed feet, but aerial birds, like swallows, have very small feet. Aquatic birds are almost helpless on land. In perching birds, the feet are " locked," so to speak, to the perches while the birds sleep. Webbed feet are found in swimming birds. The flamingo, a typical wading bird, has long legs and a long

neck. Chickens use the feet in scratching for food. Parrots use the foot as a hand. Birds of prey strike down their prey with the strong claws and hold it with the claws while they tear it apart with their beaks. In winter a fringe develops along the toes of the Grouse, enabling them to walk on the snow.

Bill.—" The bill," says Chapman, " is most important, for the life of the bird depends upon the use of the bill."

FIG. 257.—EGRET.

(Amer. Mus. Nat. Hist.)

It performs all the services of a hand, since the front limbs are already modified for another purpose. Birds dress and oil their feathers with it and some use it as a weapon. It is used in building the nest, and in procuring food, in short, it serves as a whole chest of tools.

Many birds destroy injurious insects and other animals inimical to agriculture. Most birds of prey are thus beneficial. They feed on field mice, ground squirrels, rabbits and other animals. Cooper's hawk is an exception, its food being wild birds, poultry, and pigeons. The crow and the sap-sucker could be dispensed with. Vireos, cuckoos, and woodpeckers

destroy leaf-eating insects. Quail, meadow-lark, orchard oriole, house wren, mocking-bird and some sparrows feed on insects of the farm fields when the insects are breeding. The most valuable service consists in destroying seeds of weeds. The meadow-lark, quail, cow-bird, red-winged blackbird, and many wild sparrows are especially valuable. Domesticated birds produce an income to man of millions of dollars annually. The ancestor of the common fowl was *Gallus bankiva*, the Jungle fowl of India. Domestic pigeons have been produced from the wild blue rock pigeon, *Columba livia*, of Europe, Asia and China; domestic geese from the *Anser anser* of England; most of the ducks from the wild mallard *Anas bocas*. The early New England settlers found the wild turkey. It is said that our domestic turkeys originated in Mexico.

Birds have a close structural similarity with Reptiles. Some one has called them glorified reptiles. The biologist believes that the evidence at hand indicates that Birds came from old reptilian ancestors. But they have traveled a long distance. From sluggish, cold-blooded, scaly, and—to most people—loathesome reptiles, birds have risen to active, warm-blooded, beautifully feathered creatures. The mental attitude of man toward Birds is just the antithesis of his feelings toward Amphibia and Reptiles.

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CHAPTER XXI

PHYLUM X. SUB PHYLUM II. CLASS VII. MAMMALIA

General Characteristics.—The Mammals are placed at the upper end of the Animal Series. One reason is that man belongs to this group. There is no doubt that many of the Mammals surpass all other animals in intellectual superiority. Correlated with this is a higher degree of supremacy over nature. The very name of the group, given by Linnaeus, carries with it a reference to a phenomenon which is in no small sense responsible for the higher development of these forms. This is the process of nourishing the young by milk produced by the *mammary glands* of the mother. Related with this is the fact that there is a vital connection between the young and the mother within the latter's body from the time of fertilization to birth. The helpless new born are not only at first nourished by food formed in the body of the mother, but are later watched over by the mother and trained in the ways of life by the parents. Mammals are also distinguished by the presence of hair on the surface of the body. The temperature of the blood is about 98° F. and is quite constant, i.e., independent of temperature changes in the external world. This insures, on the whole, a continuous condition of activity, shared in only by the Birds. It makes it possible for Mammals and birds to conquer the temperate and cold regions of the earth. Feathers and fur are an aid to this end.

Mammals are four-legged animals. They have a neck and a tail. The skin possesses oil glands and sweat glands. A muscular partition, the diaphragm, separates the heart and lungs from the viscera and is important in respiration. The cerebral hemispheres are very prominently developed and often possess a convoluted cortex which permits the posses-

sion of a greater number of nerve cells. Posteriorly there is one opening from the intestine, the anus, and another opening for the urinogenital systems. The heart is four-chambered, as in the Birds, but the great aorta is homologous with the left systemic artery of Birds and Reptiles, or the left branch of the second branchial arch of Fishes. The lungs do not have air sacs attached as in Birds. They have a solid mass of little air sacs or *alveoli*. The ureters from the kidneys open into a bladder from which a duct, the urethra, carries the urine to the outside. Ovaries and eggs are small. In many, the testes occur in a sac outside the body. The red blood cells of most mammals contain no nuclei.

FIG. 258.—ORNITHORHYNCUS, DUCKBILL OR PLATYPUS.

I. Prototheria.—The Mammals are divided into three sub-classes. The first of these are the *Prototheria* (first beasts) or *Monotremata*, the simplest of mammals. Three species exist to-day: *Ornithorhyncus* (Fig. 258) the duck-bill or duck-mole and *Echidna* (Fig. 259), the spiny *Anteater*, both of Australia, and *Proechidna* of New Guinea. In the duck-bill, the body is covered with soft hair, while the body of Echidna has spines among the hairs. The duck-bill is about eighteen inches long. The head has a flat horizontal horny beak and the eyes are small. There is no external ear. The legs are short and the animal is " squat like " in appearance. The front feet are webbed and the tail is flat. Only the young have teeth. These are early worn away and horny pads take their place. The reproductive apparatus and

habits are very much like that of the *Sauropsida* (i.e., Reptiles and Birds). The oviducts open into the cloaca, as do also the intestine and urinary apparatus. There is one external opening for digestive, urinary and reproductive systems hence the name Monotremata. Eggs, about $\frac{3}{4}$ inch long, with yolk and a shell, are laid at the ends of burrows in river banks. The animal is also aquatic in its habits. Before hatching, the young absorb the yolk present in the egg. The females have small mammary glands whose secretions are discharged among the hairs of the abdomen

Fig. 259.—Echidna, spiny anteater.

where they are obtained by the young. The temperature of the body is distinctly lower than in that of the other mammals or birds and is somewhat more variable. The duck-bill feeds on aquatic arthropods and annelids. Echidna feeds on ants. With their fur-covered bodies and egg-laying habits the Prototheria are paradoxical. On the whole they are the most primitive, or at any rate, the simplest of mammals.

II. Metatheria.—The second sub-class of the Mammals are the Metatheria or Later Beasts. These are the Opossums of America (Fig. 260), the Kangaroos of Australia (Fig. 261), and a few other less familiar forms most of which are found in Australia. They are more commonly known

as the *Marsupials* for the reason that there is a pouch on the ventral surface of the abdomen. In this pouch are nipples or teats containing ducts from the mammary or milk glands situated between the skin and the ventral muscular wall. Fertilization is internal which is a result of cŏpulation between a male and a female. The eggs are small with no shell or yolk and develop in the lower end of the oviduct (uterus) of the female. In only eight days in case of Dasyurs, in two weeks, in the case of the opossum, and five weeks, in the case of the kangaroo, the young are "born." They are "foetus"-like in their immaturity but are able to crawl into the marsupium of the mother and there each grasps a teat and is fed upon the milk from the mammary gland. The young develop in the marsupium for about eight weeks, during the latter part of the period they are carried around on the back of the mother. The phrase "playing possum" had its origin in a habit of the opossum in which the animal, when suddenly discovered, acts "dead to the world." It may breed three times a year and each female may produce more than thirty young annually. The opossum, *Didelphys virginiana*, is a tree-dwelling form. It eats insects,

FIG. 260.—DIDELPHYS VIRGINIANA, OPOSSUM.

(Amer. Mus. Nat. Hist.)

berries, nuts and young animals. Its meat is considered a great delicacy in our own South.

The kangaroos are found in Australia. The many species differ in size, the largest being four to five feet in height. The gray kangaroo lives on the plains of Eastern Australia and is as large as a man. The front limbs are small and weak and are used somewhat as hands. The hind legs are large and powerful. The long and heavy tail acts as a balancing organ in leaping and when the animal comes to rest. the tail and two hind legs act like a three-legged stool and so insure a stable support. The hind foot is modified for

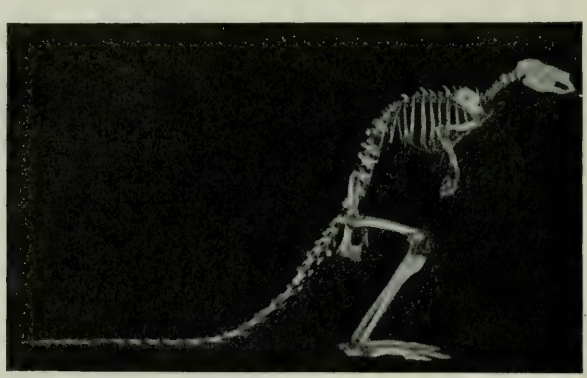

FIG. 261.—SKELETON OF KANGAROO, MACROPODUS.

rapid movement mostly in jumping. The fourth toe is very long and prominent. The hind foot resembles that of the two-toed ostrich though the latter animal moves rapidly by running. The kangaroos are herbivorous. At times they have damaged crops to a considerable extent. The stomach and intestine are structurally adapted to plant food.

Wallabies are smaller kangaroo-like forms living in the bush. Some of them are about as large as a rabbit. Wombats are small marsupials, bear-like in appearance, living upon the ground and feeding on vegetation at night. The phalangers are small arboreal forms which have a flap of skin on each side which gives them some power of aerial

navigation. The peculiar incidence of Marsupials to Australia, where they form the only indigenous mammalian population has been of the greatest interest to the student of geographical distribution of animal life. Fossil Marsupials have been found in South America.

III. EUTHERIA

General Characteristics.—The third sub-class of Mammalia are the *Eutheria* or *Real Beasts*. They are vivipar-

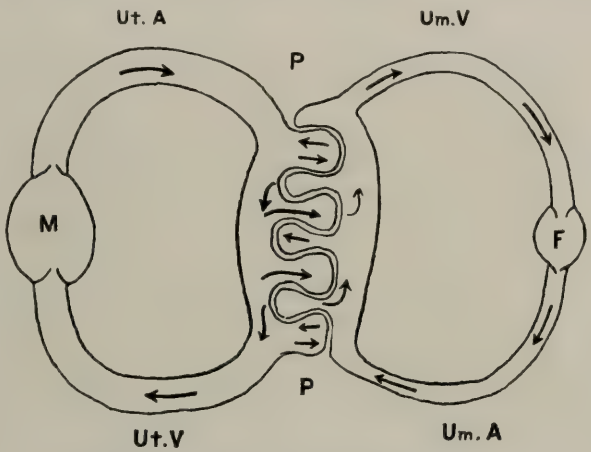

FIG. 262.—DIAGRAM OF FOETAL CIRCULATION.

M., Heart of Mother; *Ut. A.*, Uterine artery; *Ut. V.*, Uterine vein; *F.*, Foetal heart; *Um. V.*, Umbilical vein; *Um. A.*, Umbilical artery; *P.*, Placenta. No other blood vessels indicated.

ous and are sometimes called the *Placentalia* or *Placental Mammals* because the embryonic form of nutrition is by means of a structure called the *placenta*. This is partly embryonic and partly maternal in origin. It assumes various forms in different orders. It is formed against the inner wall of the uterus of the female. A long stalk, the *umbilical cord*, consisting of connective or supporting tissue and arteries and veins, connects the blood vascular system of the embryo to the placenta. Prominent arteries

and veins connected with the mother's circulatory system also extend to this placenta. The placenta therefore is an organ where the blood system of the mother and the foetus become adjacently placed. *Blood from the mother does not flow directly through the blood system of the foetus.* To understand this better (Fig. 262) the following analogous illustration may be useful. Suppose a large reservoir is supplied with a pump (heart of mother) containing an efferent tube (artery) through which a fluid containing minute particles is pumped. This reservoir is provided with another afferent tube (vein) through which this fluid is returned to the reservoir. Somewhere outside the reservoir and between the efferent and afferent tubes is a complicated irregular network of finger-like processes or compartments like enormously enlarged capillaries. The fluid is pumped through the artery to this system of sinuses and back through the veins to the maternal heart. But interlocking with these enlarged capillary sinuses of the mother are similar thin-walled enlarged capillary sinuses connected on the one hand with the umbilical vein, and on the other with the umbilical artery of the foetus, and both of these with the heart and other circulatory apparatus of the foetus; so that the foetus has four parts also—circulatory pump, efferent tubes (arteries), afferent tubes (veins) and capillary sinuses all interlocked with the blood sinuses (spaces) of the mother.

The placenta is the structure at the periphery of both systems where the blood sinuses of the mother and foetus meet. It is to be remembered that the blood of each system is separated by a double-walled, thin membrane. One wall belongs to the maternal blood sinuses and the other to the foetal blood sinuses. The mother's blood contains plasma, red corpuscles and white corpuscles. The foetus also has its own red and white corpuscles and in a sense its own plasma. Neither the red nor white blood cells nor any other particles of the mother blood pass through the surrounding membranes into the foetal circulation. However, dissolved foods pass from the mother through the permeable membranes of the sinuses of the placenta into the umbilical vein of the foetus. Arriving

at the foetal heart, they are distributed to the various developing organs by the foetal circulation. In the same manner, waste matters of metabolism in the blood of the foetus are pumped out through the umbilical artery to the placenta and here they find their way into the circulatory system of the mother who excretes them in addition to her own. The foetus is in a real sense a parasite upon the mother.

The offspring is helpless and dependent for a time even after birth. It is recognized that the prenatal and postnatal care of mammalian young constitute an important factor in the dominance of this group. Only fluid substances can pass across the membranous barrier between mother and child. The eggs are very small, no yolk is present, and fertilization is of course internal. There is a separate opening for the urinogenital system and intestine. The posterior ends of the oviducts are fused and there is also a fusion of the uterine part of the oviduct in many mammals. Due to a longer period of intra-uterine development there is a reduction of the period of nutrition of young by the mammary glands as compared with Marsupials.

The temperature of the body is higher than that of two lower sub-classes and is more constant. It varies from 35° C. to 40° C. The cerebral hemispheres become relatively larger and more convoluted among the higher groups. We find that these Mammals are adapted to live in different environmental conditions and that structural modifications accordingly occur. For example, the rabbit is a typical *terrestrial* animal, the horses and cattle are *cursorial* and adapted to swift running over the ground; the dogs and cats are *terrestrial* forms, but not as completely *cursorial*, as they still use the limbs for other purposes; the sloth is adapted to life in trees, or *arboreal*, the mole to burrowing in the ground or *fossorial*, the porpoise to swimming life or *natatorial*, and the bat is *aerial*—or a flying mammal (Fig. 341).

Orders of the Eutheria

Order I. Insectivora.—These are regarded as the most primitive members of this sub-class. They are small mam-

Fig. 263.—Talpa, the mole.
(Amer. Mus. Nat. Hist.)

mals and most of them feed on insects and worms. The body is covered with soft fur as a rule. The moles (Fig.

Fig. 264.—Brown bat, vespertilio.
(Amer. Mus. Nat. Hist.)

263) (*Talpa*) are burrowing animals with the forefeet adapted for burrowing (fossorial) habits; no external ears and only rudimentary eyes are present.

Order II. Chiroptera (Wing-like Hands).—These are the bats (Fig. 264). The forelimbs are modified for flying. The bones of the forelimb and especially of the fingers are elongated. A fold of skin extends across them and alongside the body and the hind limb to form a flying organ. The thumb is short and weak and clawed. The hind limbs are short and weak. The brain is primitive like that of the Insectivora. The smaller types of bats are insect eaters. They are quies-

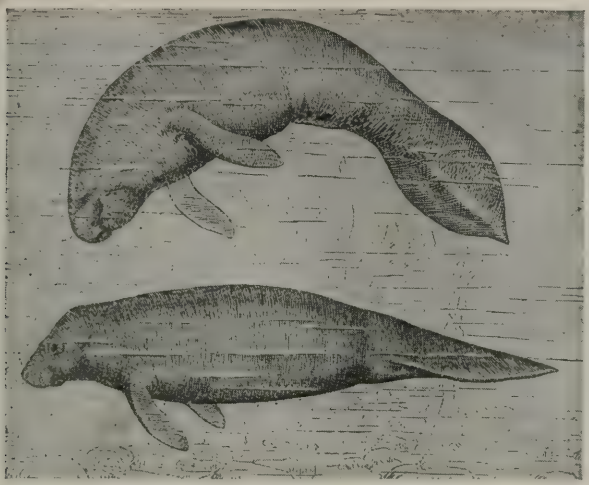

FIG. 265.—MANATUS, MANATEE.

(U. S. Bur. Fish.)

cent and hidden by day but become active at night. Some investigations indicate that they are not guided wholly by sense of vision—but that the reflection of sound waves from walls or solid objects are carried to some sense organ with the result that bats never collide with solid objects in the dark, although their rate of flight is extremely rapid. Some large bats of Australia are fruit eaters. They are called flying foxes. The body may be a foot long and the wings five feet across.

Order III. Sirenia.—These are popularly known as sea-cows (Fig. 265). They are sluggish, aquatic, heavy-boned

herbivorous mammals. They are primitive, but much modified from their early ancestors and live in rivers or near the mouths of rivers. The hide is thick and tough and possesses little hair. They have flipper-like forelimbs, but no hind limbs. The Florida manatee is about nine feet long and is now very rare. The first idea of sirens may have come from sailors' exaggerated stories of these beasts.

Order IV. Cetacea.—These are the whales (Fig. 266), porpoises (Fig. 267) and dolphins. They are truly aquatic

FIG. 266.—ORCA-KILLER WHALE.

(Amer. Mus. Nat. Hist.)

and natatorial with fish-like bodies, and have lost the hair so characteristic of the mammals. The forelimbs have become paddles, the hind limbs are gone, the tail is flattened horizontally into a *fluke*. There is usually a middle dorsal fin. A thick layer of fat or blubber under the skin aids in maintaining the high constant temperature, even in ice cold waters. The body is torpedo-shaped. There are no external ears. The larynx is long and meets the internal nostrils so that there is a continuous passage-

way for air from external nostrils to lungs. Cetacea do not breathe as often as other mammals. In expiration the animal *blows*. This leads to the wrong impression that in expiration these animals spout a column of water. All are *carnivorous*. Many of them live in groups.

One group of Cetaceans possesses teeth. These are the dolphins (*Delphinus delphis*), porpoises (*Phocaena communis*), killer whales and sperm whales. Sperm whales seventy-five feet long have been found. They feed principally upon

FIG. 267.—PHOCAENA, PORPOISE.

(Amer. Mus. Nat. Hist.)

squid. The killer whale is everything its name signifies. The narwhal has a long, twisted bony beak in front.

True whales do not have teeth, but possess plates of baleen or whalebone which hang from the palate filling the mouth like a sieve. They take in great quantities of water which passes through this whalebone sieve retaining all small animals which are used as food. The largest of all living animals, the sulphur-bottom whale, belongs to this group. It occurs in the Pacific Ocean from California to Central America. Some specimens taken were nearly 100 feet long and had a weight of nearly 150 tons. An eighty-foot whale may have a baby twenty-five feet long.

The whaling industry yields an annual income of

about $70,000,000. It is a gamble as to whether whales will be found or not. There are many " off " years. Half of the world's catch of whales is obtained near the sub-antarctic islands, the South Shetlands and Kerguelen. The Norwegians are the leaders in this industry. Fresh whale meat is eaten in Norway. It tastes somewhat like beefsteak flavored with fish. Formerly whale oil was used in the manufacture of soaps, and as a lubricant. Sperm oil is obtained from the sperm whale. In 1922 the New Bedford whalers obtained over 150,000 gallons of sperm oil. It is used in lubricating light machinery. Spermaceti (i.e., something from sperm whales) is a white, crystalline, tasteless, odorless brittle wax. It is used in the manufacture of cosmetics especially " cold creams " and is a by-product of sperm oil. Whalebone is light, elastic and flexible. Japanese make beautiful little cases, sandals, etc., out of whalebone. Ambergris is a substance from the intestinal tract of the sperm whale. Pieces varying from a few ounces to 200 pounds have been found in the water or washed up on the shore. It is a solid waxy substance ranging from mottled gray to black in color, and is used as a fixative in fine perfumes. Forty-four pounds taken in 1922 had a value of about $250 a pound.

Order V. Edentata.—These are armadilloes, sloths (Fig. 268) and anteaters (Fig. 269). The existing forms are but a few survivors of more extensive ancient types. Survival was insured by adaptive modifications in structure brought about by adoption of various modes of life. Some are *fossorial,* some are *arboreal*—some have their bodies covered with a strong protective armature. The Nine-banded Armadillo is found in Southern Texas. It has an armor of bony plates. The Texas form has nine bony rings about its body. If attacked it can roll up into a ball in which condition it is protected from most enemies. Armadilloes eat worms and insects. Strong claws for burrowing are present. The tongue is long and can be protruded. The Anteaters (*Myrmecophaga*) are hairy forms. There are no teeth present and the skull is elongated and tapering. The tongue is very long and is used for " licking up " ants. The fore-

feet have long claws for scratching open ant hills. The tail is long. Some forms are *arboreal.* They have prehensile tails. Anteaters are found in South America. Sloths inhabit the forests of South America. They live almost entirely among the branches of trees and eat fruits, leaves and young buds. The front legs are longer than the hind legs, and the animals hang suspended from branches

FIG. 268.—CHOLOEPUS; TWO-TOED SLOTH.

(Amer. Mus. Nat. Hist.)

and crawl along this way, attaching themselves by means of the long curved toes. The body is covered with long shaggy hair.

Order VI. Rodentia.—These are gnawing animals—mice, rats, chipmunks, squirrels, rabbits, woodchucks, beavers (Fig. 270), and porcupines. The incisor teeth are long and chisel-like. With persistent use the teeth are kept sharp. They also grow continually. There are no canine or eye teeth. Most rodents are small forms and most of them are

terrestrial. There are more species of Rodents than of any other order of mammals. Most of them are vegetarians.

FIG. 269.—MYRMECOPHAGE—LESSER ANTEATER.

(Amer. Mus. Nat. Hist.)

Prairie dogs live in burrows in colonies or villages on the Western plains. Woodchucks or ground-hogs live usually a solitary existence in burrows in open grassy places, fattening up during the summer on grasses in preparation for the long winter sleep—coming forth on Ground

Hog day—if there is to be an early spring, according to popular superstition. Beavers live in the water. The hind feet are webbed, and there is a broad flat tail which is used as a trowel in plastering mud in the construction of dams, which are made across a stream. Trees are gnawed and felled for this purpose. In the pond thus made they build their nests or houses—the entrance being under water. It is a castle with a moat about it. The pocket gophers live in burrows in fields. They rob the grain and are a distinct

FIG. 270.—BEAVER COLONY.

(Amer. Mus. Nat. Hist.)

menace to the farmers of the West. Muskrat skins are sought after by trappers as there is good market for them. The porcupines have long spines on the back. When the animal is disturbed, contractions of muscles in the skin raises these spines, thus affording ample protection.

Order VII. Ungulata.—These are hoofed animals and include a heterogeneous collection of horses, cattle, sheep, goats, pigs, deer, elephants, hippopotamuses, camels, tapirs, rhinoceroses, etc. They are *terrestrial*, *herbivorous*, and use all the four limbs in locomotion. They do not walk on the soles of the feet as is usually the case but upon the toes.

The canine teeth are small or absent. The Ungulates are divided into several sub-orders.

Sub-order 1. Artiodactyla.—These are cattle, wapiti (Fig. 271), pigs, peccaries, camels, hippopotami, giraffes, antelopes, sheep, goats, elk, moose, bison (Fig. 272), musk-ox, reindeer, etc. They are even-toed animals. In these forms the third and fourth toes are large and equally developed. The axis of the limb passes between these toes. They tend to have a complex stomach. Cattle, sheep, deer

FIG. 271.—CERVUS CANADENSIS—ELK OR WAPITI.

(Amer. Mus. Nat. Hist.)

and giraffes are true ruminants. The stomach has four compartments. The food, being grass or hay, passes down the oesophagus into the (*a*) paunch or rumen. This is a large sac and serves to soften the food. The food then is forcibly returned to the mouth. Here the cud is thoroughly chewed at leisure and mixed with saliva. It is then swallowed a second time, but now passes into the (*b*) reticulum, the inner walls of which are honeycombed. Then it passes on into the (*c*) *psalterium* and from this to the true stomach or (*d*) *abomasum* where the gastric juice is secreted. From this

it passes to the duodenum. Peccaries are small, black, pig-like animals living in the woods of some parts of America and feed on roots and nuts. The horns of deer are shed annually. The moose has enormous antlers. It lives in northern American woods and feeds on bark, twigs, leaves and lichens. The elk are the largest of the round-horned deer. The greatest number of elk now left is found around

FIG. 272.—BISON.

(From specimens presented to American Museum of Natural History by Buffalo Bill, W. F. Cody.)

the Teton mountains near Jackson Lake, Wyoming. Rocky Mountain goats are still found in British Columbia. Some of them weigh over 250 pounds. They live among rocky fastnesses, negotiating steep mountain sides with ease. Millions of bison in great herds roamed the western plains of America about fifty years ago. The wholesale slaughter of this valuable animal together with the development of the country has almost caused its extinction. There are only about two thousand specimens in existence to-day.

The smaller musk ox is able to exist in the Arctic regions and is of great value to Eskimos.

Sub-order 2. Perissodactyla.—These are horses, asses, zebras, tapirs and rhinoceroses. The third toe of each foot is larger than the others and the axis of the limb divides this toe. It is the only complete digit in the horse. Many

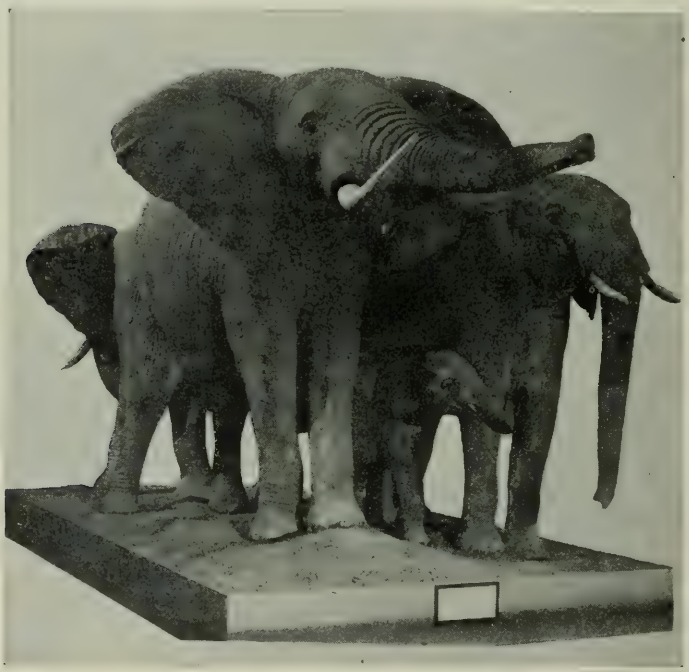

FIG. 273.—ELEPHAS AFRICANUS.

(Mounted at American Museum of Natural History by Carl Akeley.)

fossil horses have been found in America. All our domestic horses were introduced here from Europe. The stomach of Perissodactyla is simple. Tapirs have a prehensile snout. Rhinoceroses are large, thick-skinned animals with a single horn on the nose in some species; in other species with another horn on the face as well. They are fierce, belligerent animals in spite of the fact that they are vegetarians feeding on leaves and grass.

Sub-order 3. Proboscidea.—These are the Elephants (Fig. 273). The nose is prolonged into a *proboscis* or trunk, which is a tool with many uses. One pair of upper incisors form long tusks composed of ivory. At the end of the proboscis are the nasal openings. The teeth are of great size and the grinding surfaces, provided with lateral ridges, are veritable mills. There are five digits on each foot. When standing, they have the appearance of a great mass supported by four straight columns at the corners. The structure is adapted to standing. It is said that some elephants probably never lie down in the hundred years or so of their existence. Yet they can travel at great speed, smashing their way through the brush with ease. However, they ordinarily use well-worn trails which they have constructed. The Indian elephant has been more or less domesticated, and is a most useful laborer. Their mental organization is unstable and at short notice they may change to fierce ponderous machines of destruction. They are the largest of land mammals. As is the case with other large mammals, they are becoming extinct.

Order VIII. Carnivora.—These are flesh-eating animals. They are mostly ground dwelling, coursing forms. There are usually four toes on each foot and the toes are supplied with claws. The limbs have other uses beside locomotion. They are used in striking down the prey in fighting, and in holding the food while the animal tears it apart with its teeth or vice versa. The dentition is adapted to the type of food. Some are *omnivorous* and a few vegetarian. A prominent characteristic is the presence of long, pointed canine teeth whose uses are self-evident. Some of the teeth further back in the jaws (premolars) act on each other like scissors for cutting flesh. The stomach is simple and the intestine is short, because the food is concentrated. They are fearless, aggressive, intelligent animals, keen of vision, hearing and smell, their movements full of grace and beauty oftentimes marred by stealth and cunning.

They are divided into two great sub-orders. 1st, Fissipedia, 2d, Pinnipedia.

1. Fissipedia.—The Fissipedia are mostly terrestrial

forms. Among the commoner groups of Fissipedia are the families:

a. Felidae.—The true cats with retractile claws including the domestic cat, wildcats, lynx, puma, jaguar, leopard, tiger and lion.

b. Canidae or dog-like forms with non-retractile claws,

FIG. 274.—URSUS, BLACK BEAR.

(Amer. Mus. Nat. Hist.)

including the domestic dogs, the wolf, fox, jackal, coyote, and raccoon.

c. Ursidae.—Plantigrade, i.e., they rest the whole sole of the foot on the ground. The tail is short—the body is "stocky." These are the bears. The black bear (Fig. 274) Ursus americanus, is the most common form. It eats fish, berries and honey. The larger grizzly bear, Ursus horribilis, is still found in the Rocky Mountains.

Bears appear to be clumsy creatures. But if need be they can move with great agility, they can strike powerful blows with surprising rapidity and can travel at great speed. In the Yellowstone Park, where they have been protected and fed, although they live in a wild state they approach man and the automobile fearlessly. Bears exhibit a considerable degree of intelligence. The badger, marten and weasel are examples of a number of small American forms belonging to the group.

FIG. 275.—FUR SEALS.

(Amer. Mus. Nat. Hist.)

d. Mustelidae.—The skin of a single sea otter has sold for a thousand dollars. The mink, semi-aquatic, is very destructive of small animals such as fish and birds. The skunk when surprised or disturbed can emit from scent glands, near the root of the tail, a secretion which has an almost overpowering odor.

II. Pinnipedia.—The sub-order Pinnipedia includes the sea lions, seals and walruses. The forelimbs are modified and form paddles or flippers for aquatic locomotion. The hind limbs are present and folded back like a double tail. Both front and hind feet are webbed. Their body is cov-

ered with fur. They possess the power of land locomotion to a considerable extent.

The sea lions, *Otariidae*—the eared or fur seals, are the most terrestrial and use both pairs of limbs on land. They live on fish. While spending most of the time at sea, they return each year to some rocky shore for breeding. They are polygamous—each breeding male controlling a harem of many females. The males fight to gain this supremacy. The unsuccessful males are called " bachelors." The walrus has long, dependent, canine teeth. Some specimens weigh 2000 pounds and are twelve feet long. The true seals, or *Phocidae*, have no external ears. The hind limbs are permanently stretched backwards. They are more exclusively aquatic than sea lions or walruses. Fur seals (Fig. 275) have been hunted for about a hundred years. The hunting grounds are now limited to the Pribilof Islands in Alaska. *Callorhynus alsacanus* is the fur seal of these Islands. It is only the young males that are legally taken now as they would probably die naturally before they reached maturity. The hide and fur of the real seal is of great value.

Order IX. Primates.—This order is placed at the end of the Animal Series chiefly because it includes *Man*. After all, man is the most highly developed, the most specialized of all animals. He not only shows greater supremacy over all other animals, but over all nature as a whole. Included in the lower primates are animals which do not appear to resemble man at all closely, but on account of certain morphological grounds they are all grouped as the order Primates. Most Primates live in warm countries. The opposable nature of the great toe and thumb enable them to be arboreal animals. They will eat almost any form of food, although some prefer fruits or insects. In many structural features they are more generalized than the other orders although the front limbs and especially the hands are highly specialized in some. The brain is on the whole more highly developed than in other forms. Primates are divided into six families.

1. *Family Lemuridae.* (Fig. 276).—These are the lowest. They are small quadrupeds with long tails. The facial region is elongated, the hind legs are longer than the fore-legs. They are very abundant in Madagascar. Their

FIG. 276.—VARIED LEMUR, MADAGASCAR.

(Amer. Mus. Nat. Hist.)

faces resemble those of foxes, but their bodies are monkey-like. They link the lower mammals with the higher primates.

2. *Family Hapalidae.* (Fig. 277).—These are the small arboreal marmosets of South America. The tail is long. There have prominent ears. The big toe has a flat nail. They are often kept as pets.

3. *Family Cebidae.* (Fig. 278.)—These are the South American monkeys or New World monkeys. They are small active animals and are most common in Brazil. The tail is long and prehensile, the thumb and big toe are opposable. The digits bear nails and not claws. The

FIG. 277.—MARMOSETS.
(Amer. Mus. Nat. Hist.)

howling monkeys are so called on account of the frightful noises they make to drive away enemies. Spider monkeys are slender long-limbed forms with no thumb but a long prehensile tail.

4. *Family Cercopithecidae.*—These are the Old World monkeys, found in Asia and Africa. The snout is dog-like.

The tail is not prehensile, but may be long. The Macaques are common in all zoological collections of living animals and are easily kept in captivity. The male Mandrill has a brilliantly colored face and hips. The Baboon from Africa does not live in trees but among rocks.

5. *Family Simiidae.*—These are sometimes called the *Anthropoid apes* because of their resemblance to man. They include the Gibbon, Orang-utan (Fig. 279), Chimpanzee

FIG. 278.—HOWLING MONKEYS.

(Amer. Mus. Nat. Hist.)

and Gorilla (Fig. 280). The breast bone is short and broad. Arms are longer than the legs, there is no tail; they tend to walk on the edges of their feet, a most convenient position in climbing trees. Gibbons are found in Southeast Asia. They are mostly arboreal and are omnivorous eaters. They walk erect and are about three feet long. Orangs are at home in Borneo and Sumatra in swampy regions. They are assisted in walking by placing the knuckles on the ground. They live in nests in trees and are vegetarian. Their brain is quite like that of man. They are about four feet high.

The Chimpanzee is about 5 feet high and inhabits Equatorial Africa. It lives in nests in trees, and eats fruits. The arms are not as long as the legs. Chimpanzees become domesticated and are easily taught. They become quite human-like in many ways and are very intelligent. The Gorillas live in Western Equatorial Africa. They are the largest of the Anthropoid apes and heavier than man though not as tall. They may weigh five hundred pounds and are

FIG. 279.—ORANG-UTANS.

(Amer. Mus. Nat. Hist.)

powerful animals. They walk on the soles of the feet aided by the hands. Formerly they have been described as ferocious and untamable animals, but recently Akeley testifies to the opposite of this. Gorillas have been successfully "tamed" by Miss Cunningham of England, who found that the animals she trained showed indications of considerable intelligence and in fact were affectionate.

6. *Family Hominidae.*—This family contains the form *Homo sapiens*—human beings. Man differs anatomically from other primates in the great development of the brain,

in the erect posture and longer hind limbs. In locomotion the soles of the feet are flat upon the ground, the great toe

FIG. 280.—GORILLA, "JOHN DANIEL."
(Amer. Mus. Nat. Hist.)

(*hallux*) is not opposable, the heel is better developed. With the upright posture and with head erect he has a greater

view of the environment and the voice mechanism is highly developed. His anatomy, however, shows in some other respects a generalized condition. For example, the digestive tract is more generalized than that of the Ungulata. In limb plans he is more like a frog than either horse or cow.

In respect to specialization it is the brain, voice and hand that have departed most from the generalized condition. There is less hair on the body than most Primates have, and the forehead is more prominent, the face less extended. The canine teeth are small. There is no tail. The gorilla and man are anatomically more similar than the gorilla and monkey. Truly, as Richard Owen said, " There is an all-pervading similitude of structure between man and the higher apes." A further account of the biology of man is given in later chapters.

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Part IV.—GENERAL BIOLOGY

CHAPTER XXII

COMPARATIVE ANATOMY

Introduction.—The preceding pages give an account of the various types of Plants and Animals, the special morphological characteristics of each group and its subdivisions, together with references to various methods employed in carrying out the physiological functions necessary to life. As presented, the features common to all are not emphasized. Nevertheless, in the midst of such a great variety of structures, there is a surprising unity. A review is now necessary in order to see whether there is any indication of *similarity in morphological structures* and *physiological functions*.

This problem could be satisfactorily pursued with either Plants or Animals, but, from a morphological point of view, the attempt to bring the two groups together into the same category would not be attended with much success, because each has such a different structural plan. One reason for the difference in organization is that these groups are differently adapted to the world about them. The simplest plants and animals are very much alike, but as we proceed from the simplest of each to the most complex, the structural plans diverge more and more.

It would be entirely feasible to attempt a general comparative morphology of either plants or animals, but in our brief discussion there is room for but one. As human beings we are probably more interested in animal morphology in general, and in Vertebrates in particular. Therefore, in the succeeding three chapters, a few generalizations from *Animal Anatomy*, *Histology*, and *Embryology* will be presented. The discussion of the reproductive organs will include a review of the different types, and then will follow

an analysis of the different physiological processes. Next a brief presentation of the distribution of animals in space or Geographical Distribution, and the distribution of animals in time or Palaeontology. One of the questions, that is the subject of much research at the present time, is Heredity, and some results of investigations of this biological problem will then be presented. The study of organisms in a systematic relationship, and the review of paleontological and other evidence leads to the assumption that in this world of ceaseless change, there has been an evolution of organic life. This will be considered, and finally Man's Place in Nature will conclude the account.

The student is now able to study changes in organization that have occurred in the various groups as a result of which the various physiological processes are more effectively carried out. There are three great groups of physiological processes: (*a*) those concerned in *Metabolism*, (*b*) those concerned in *Adjustment*, and (*c*) those concerned in *Reproduction*. By what sort of organs are these carried out in the various groups? In the answer to this question special emphasis is given to the Vertebrata.

I. Organs Related to Metabolism

The following processes are associated with metabolism: 1. *Digestion*. 2. *Respiration*. 3. *Circulation*. 4. *Excretion*. The organs involved in performing these functions in animals are now studied comparatively.

1. Digestion.—*a. Lower Animals.* Neither Protozoa nor Sponges have organs of digestion. In Coelenterates there is a blind sac with one opening serving as a mouth and anus. In Hydra this sac is somewhat tubular in form and is composed of endoderm cells. Endoderm appears early in the development of higher animals and forms the lining of the digestive tract in all of them. It also forms glands whose secretions are concerned in digestion. In the Flatworms the digestive tract is still a blind sac of endoderm, but the sac is not a simple tube. It has many diverticula and extends to all parts of the body. In the Roundworms

there is a straight intestinal tract with mouth and anus. In Annelids the digestive tract shows indications of specialization. The Earthworm has a pharynx, oesophagus, crop, gizzard, and intestine. The crop and gizzard may be considered a sort of stomach. In Arthropods the arrangement is somewhat similar, that is, mouth, oesophagus, stomach, and intestine, though the tube shows various special structures in different groups of this phylum. Studied

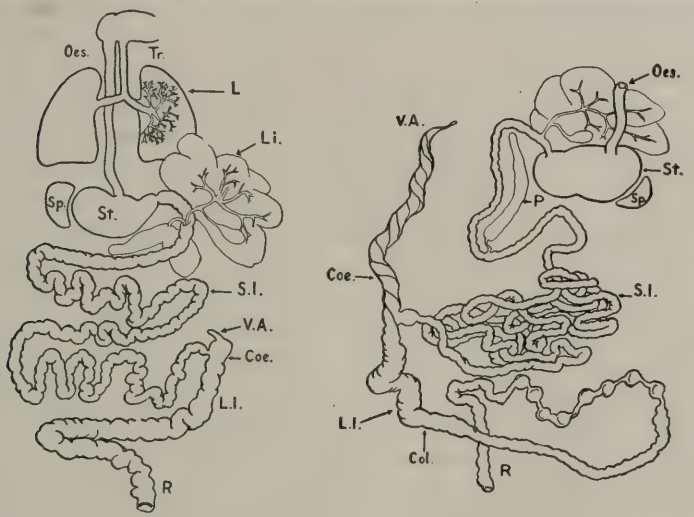

FIG. 281.—AT LEFT, DIAGRAM OF DIGESTIVE TRACT OF CAT; AT RIGHT, DIAGRAM OF DIGESTIVE TRACT OF RABBIT.

Oes., Oesophagus; *Tr.*, Trachea; *L.*, Lung; *Sp.*, Spleen; *St.*, Stomach; *P.*, Pancreas; *S. I.*, Small intestine; *Coe.*, Coecum; *V. A.*, Vermiform appendix; *L. I.*, Large intestine; *R.*, Rectum; *Col.*, Colon; *Li.*, Liver.

from the viewpoint of the kind of food eaten, these special structures are seen to be adaptively modified.

b. Vertebrates.—A striking similarity of plan is seen in the digestive tract of Vertebrates although the general plan shows ample adaptive modifications (Fig. 281). Associated with the mouth are (*a*) *teeth*, (*b*) from Amphibians upward, *salivary glands*, (*c*) *tongue* glandular and sensory. In forms above Fish (including Dipnoi) the nasal sacs open into the mouth.

The mouth leads into the *pharynx*. On the walls of this in fishes are *gill clefts*. The *Eustachian tubes* of higher Vertebrates are the modified *spiracular clefts* of Elasmobranchs. The gill clefts functional in Fishes and Amphibians are present only in the embryos of Sauropsida and Mammals for a short time. The skeletal supports of the gills of Ichthyopsida are modified for different uses in higher forms. The *thyroid* and *thymus glands* are associated with the pharynx, arising from it in the embryo but later losing their early close connection. Associated with the pharynx is the *swim bladder* of fishes, which may originate dorsally, and in land Vertebrates the lungs, which originate ventrally. These outgrowths of the digestive tracts are not concerned with digestion. The pharynx leads into the *oesophagus*. This simply carries the food down to the *stomach*. The stomach is an enlargement of the digestive tube where food undergoes a partial simplification or digestion. On the whole it is saccular in form. Two portions are recognized,—the *cardiac* or oesophageal end, and the *pyloric* or intestinal end.

Different types of glands are present in great numbers in the wall of the stomach. The special modifications of the stomach in birds and ruminant mammals are recalled here. Animals could do without a stomach if they were given the form of food the stomach prepares. Close behind the stomach of most Vertebrates are found two glands connected with the first part of the intestine next to the stomach. These are the *liver* and the *pancreas*. They have to do with the digestion of food within the intestinal tract or metabolism elsewhere. The intestine is divided into two portions: a longer small intestine of small diameter and a shorter large intestine of large diameter. Most digestion occurs in the *small intestine*. Its internal surface is increased by various folds or outgrowths and its wall contains multitudes of glands concerned with digestion. In the *large intestine* the unabsorbed material is prepared for expulsion or defecation. At the junction of the small intestine and large intestine of Mammals there is a pouch, the *coecum*.

Extending from the end of this there is a diverticulum

called the *vermiform appendix*. This is very long and tubular and important from a digestive point of view in herbivorous forms like the rabbit. It is very short and rudimentary in Carnivora like the cat. Infection developing in this appendage often leads to fatal cases of blood poisoning. Early surgical removal of the appendix usually cures appendicitis. The length of the digestive tract depends on the kind of food eaten. Herbivores have a tube about twenty-five times the length of the body while that of Carnivores is only about five times the length of the body. Similar differences prevail among animals of other groups, for example, Insects. Parasites, such as tape worms, have no digestive tracts. Organs which are not used degenerate and may disappear altogether. The appendix of the rabbit functions actively while in the cat it has no apparent use and has almost disappeared. The hind gut ends in the *cloaca*. Into this, in all Vertebrates except the higher Mammals, the ureters and goniducts open. In Amphibia, there grows out ventrally from it the *cloacal bladder*. In the higher Vertebrates this is represented in the embryo by a foetal structure called the *allantois*, concerned with embryonic respiration and nutrition. The bladder of Reptiles, Birds and Mammals develops from the base of this. In the higher Mammals the cloaca becomes divided into a faecal portion associated only with the digestive tract and a urinogenital sinus, the terminal portion of the urinogenital systems.

From a simple straight tube in lower forms the digestive tract has become a long-coiled exceedingly complex structure with many special structures concerned in doing more effectively, extensively, and completely the various jobs concerned in digestion. Its chief work is to convert food into a form in which it may be used by the body cells and to separate the useful from the useless portion.

2. Respiration.—Protozoa, Porifera, Flatworms, Roundworms, and most Annelids have no special organs of respiration. The surface of the body is readily permeable to the gases concerned in respiration. *Gills* appear in Molluscs. The Crustacea have gills and these organs are present

also in Fishes and in some Amphibia through life, although restricted to other Amphibia during the larval stage. A gill is an organ provided with a capillary system covered with a thin membrane and surrounded by water. Oxygen dissolved in the water can easily permeate the membrane of the gill and enter the blood of the capillary and similarly CO_2 can easily pass from the blood through the wall of the capillary and gill membrane into the water. Gills may be leaflike or like a tuft of hairs or slender processes. In Crustacea they are attached to certain appendages which move back and forth, driving fresh water to them. In some aquatic insects the hind gut is filled with platelike gills. In certain Fish, Insects, and Worms, the hind gut may be filled with fresh water from time to time and so serve as a respiratory organ. The cloacal bladder of the frog is thought to serve in this way at times.

Insects have solved the problem in another way which apparently serves the purpose well for them. Outside air is delivered directly to the various tissue cells through a complicated system of tubes called *tracheae.*

In Reptiles, Birds, and Mammals, gill clefts are formed in the embryo, and paired lungs are formed from the ventral side of the gut. In Dipnoi, the dorsal air sac is supplied with pulmonary blood vessels and serves as a sort of lung. Developing as sacs associated with the digestive tract (*pharynx*) and inside the body cavity, the lungs are protected. The respiratory surfaces continue to be moist in all forms. They are relatively simple sacs in Amphibia. The inside walls are honeycombed with little chambers or *alveoli* whereby the total respiratory surface is somewhat greater than the total external surface of the lung. In the Reptile the lung is relatively larger and more complex. There is a great increase in the number of air sacs or alveoli and in the interior of the lung of the turtle there is an open passageway. In the Bird and Mammal, this increase is carried to a further extreme. Here the lung consists of multitudes of microscopic air sacs, whose membranous walls contain pulmonary capillaries. Thus a great extension of respiratory surface is packed into a small compass.

In man, the total respiratory surface of the lung is a number of times the surface area of the body. In the frog, it is only a small part of this. However, the frog's skin also serves as a respiratory organ. The air chambers connected with the lungs of birds serve as aids to the mechanics of respiration.

The appearance of lungs in the higher Vertebrates involves a rearrangement of blood vessels, muscles, nerves, and skeleton. Some of these are especially concerned in inspiration and expiration. The change from aquatic to terrestrial mode of life has involved active pumping or suction of air into the lungs of these forms.

3. Circulation.—No special system for the conveyance of oxygen, foods, and wastes is needed in Protozoa, Porifera, Coelenterates, Flatworms, or Roundworms. When a body cavity appears and organs develop in it and the mass of cells increases, the needs of the organs and tissues are not adequately taken care of by the old-fashioned method of transfer from cell to cell or from one cell mass to a tissue space and thence to another tissue mass. This primitive method is still prevalent in the passive plant world. The term, gastrovascular cavity, used in connection with Coelenterates and Flatworms refers to the fact that the digestive tract serves the two functions of digestion and circulation. However, in the more complex animals, oxygen, food, and wastes are distributed by means of a system of blood vessels. In the higher forms these consist of a heart or muscular pumping organ, arteries which carry blood away from the heart; capillaries, which are a microscopic network of thin-walled tubes throughout the various tissues, and veins, which return the blood from the tissues to the heart. In the earthworm, the peristalsis of the body and intestine aid the peristalsis in the trunk line blood vessels and the five pairs of hearts to circulate the blood. The coelomic cavity is filled with coelomic fluid which contains food material absorbed from the intestine. There are perforations in the septa. Peristalsis therefore drives the coelomic fluid back and forth and brings the body wall and internal organs into contact with food. The open funnels of the nephridia are im-

mersed in this coelomic fluid. Possibly the primary function of earthworm blood is respiratory. Insects have an open or lacunar blood system. The heart is tubular and lies dorsal to the intestine. Short arterial trunks from the heart carry the blood forward into *lacunae* or spaces in the coelom. Here it slowly " circulates " about the tissues and then returns to the heart through lateral slits.

On the other hand, in Vertebrates there is a *closed blood system.*. The blood flows in special tubes forming one continuous interconnected system. The blood is continually leaving the heart through arteries and returning through veins. In Molluscs and Arthropods are found all grades between the open-system type and the closed system. In insects with tracheae, the vascular system is not concerned with delivery of air to tissues and the system is open. In Crustacea with gills, capillaries are needed to carry blood to tissues and the system is to a great extent closed. Of course, even in Vertebrates it is not absolutely closed, else the tissues would starve.

The heart, arteries, veins, and capillaries are structurally similar in part. Essentially tubes, they vary, according to the needs. The heart is primarily a pump with valves and hence is muscular and elastic. Arteries must withstand considerable pressure and hence are thick-walled, tough, elastic, and muscular. Capillaries are thin, fine, membranous-walled tubes. Veins are provided with valves so that the blood as it progresses toward the heart cannot return toward the capillaries. The membrane forming the wall of the capillaries also forms the lining of the heart, arteries, and veins. The heart of lower forms is a tube. (Fig. 282.) In the embryo of Vertebrates it is at first tubular, then grows into the form of the letter " S " reversed. In Fishes, it is divided into two portions, the anterior dorsal loop of the " S " widens out into a thin, saccular auricle while the posterior ventral loop of the " S " becomes the thick muscular ventricle. A valve develops between the auricle and ventricle. Venous blood from the body fills the auricle. This contracts, filling the relaxed and empty ven-

tricle. When filled the ventricle contracts, closing the valve

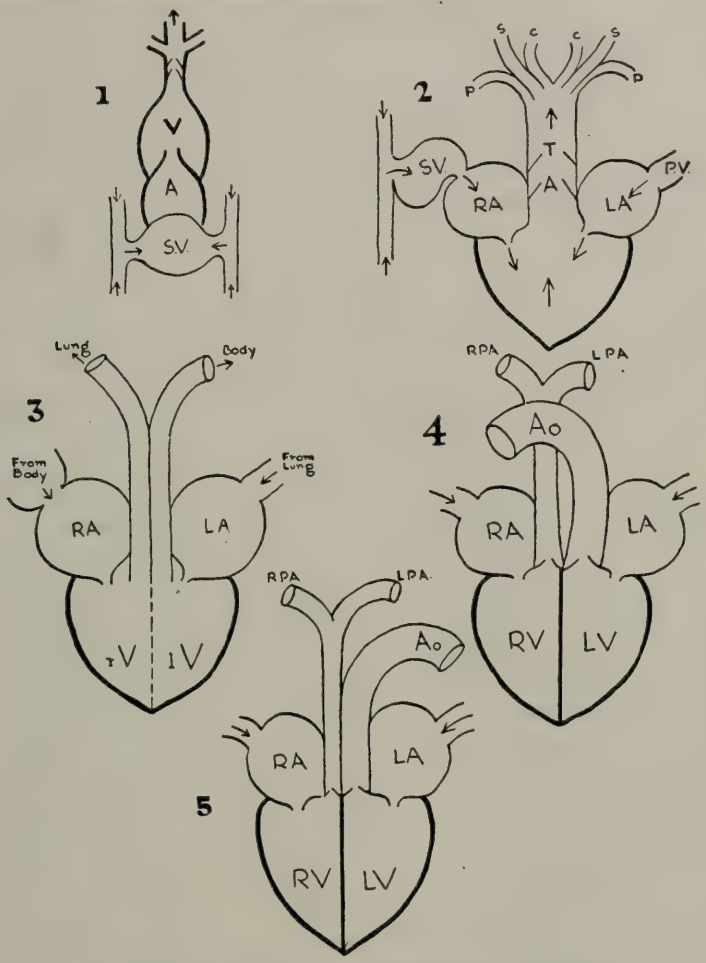

FIG. 282.—HEART OF VERTEBRATES, DIAGRAMMATIC.

1, Fish; 2, Amphibian; 3, Reptile; 4, Bird; 5, Mammal. *S. V.*, Sinus venosus; *A.*, Auricle; *V.*, Ventricle; *R. A.*, Right auricle; *L. A.*, Left auricle; *P.*, Pulmonary artery; *S.*, Systemic artery; *c.*, Carotid artery; *R. V.*, Right ventricle; *L. V.*, Left ventricle, *Ao.*, Aorta, *R. P. A.*, Right pulmonary artery; *L. P. A.*, Left pulmonary artery.
Note that aorta of Bird and Mammal curve in opposite directions.

to the auricle and forcibly driving the blood forward through the arterial system, aided by the muscular contractions of

the arteries. The fish heart contains exclusively venous blood. In larval Amphibians *the heart is similar to that of Fishes.*

But in lunged forms, like the frog, the transition from gills to lungs has brought a change in the heart, for now body or venous blood and blood from the lungs is returned to different chambers of the heart. The single auricle has become divided into two, a right and a left auricle. From the body the right auricle receives the venous blood which is poor in oxygen and rich in carbon dioxide. From the lung, the left auricle receives blood which is rich in oxygen but poor in carbon dioxide. *Both* these auricles open into *one ventricle* and the complete separation of the non-aerated blood and aerated blood is not possible. In other words, Amphibia have not completely adapted themselves to land or air breathing with their *two auricles* and *one ventricle.*

Reptiles are somewhat like Amphibia. There are two completely separated auricles, but the ventricle shows some advance. It contains a sort of partition, perforated and open it is true, but dividing it, in a way, into a right ventricle and left ventricle. It serves only fairly well to regulate the currents of blood so that non-aerated (venous) blood is directed from the right side of the ventricle to the lungs and the aerated blood from the left side of the ventricle to the body. However, strangely enough, the partition is *complete* in the *Crocodilia* where there are *two* completely separated auricles and *two* ventricles. This is also the condition in Birds and Mammals. So the heart in its evolution changes from a *tube* to a *four-chambered organ.* With the appearance of the right and left auricles and right and left ventricles, the heart has really been divided into a right half and a left half. The *right heart* is associated with non-aerated blood pouring in from the body generally, and sending it to the lungs, while the *left heart* is associated with this blood returning aerated from the lung and sending it out all over the body. The fact that so important an organ as the heart is modified in its relation to respiration indicates the importance of respiration in vertebrate life.

In describing the vascular system of the dogfish and

fishes in general (Fig. 283) it was stated that from the ventricle the blood was pumped forward into a vessel on the median ventral floor of the mouth. From this vessel branches pass to the gills. These are called the *afferent* branchial arteries since they carry blood to the capillaries of the gills. From these capillaries, blood flows dorsally through efferent branchial arteries to the dorsal aorta, which has many branches for distributing the blood to various organs of the body. These sets of branchial arteries on both sides of the pharynx extending from the ventral blood vessel to the dorsal (aorta) vessel are known as the aortic arches. Of special interest are

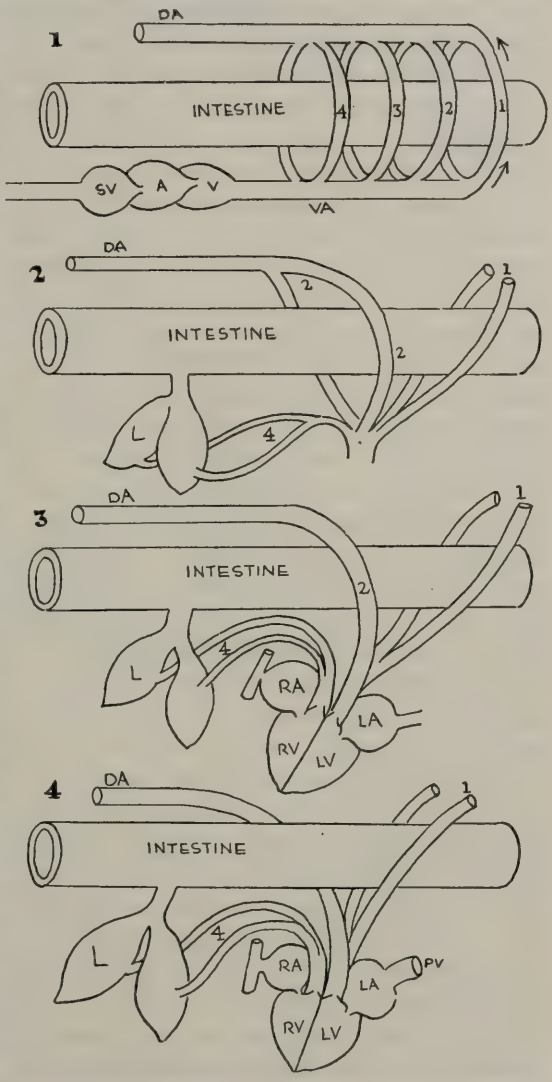

FIG. 283.—DIAGRAMS TO INDICATE PLAN OF AORTIC ARCHES.

1, Fish; 2, Amphibia; 3, Bird and 4, Mammal. 1, 2, 3, 4, the 1st, 2nd, 3rd and 4th aortic arches. *D. A.*, Dorsal aorta. (See Text.)

four pairs which are here numbered one, two, three, four,—number one being most anterior. The arrangement appears to be entirely different in Birds and Mammals. Studies in comparative anatomy, however, show a *progressive change* from what is found in Fish to that of the Higher Animals.

The arrangement in frog tadpoles is quite like that of the fish. But when metamorphosis occurs and the fish-like tadpole becomes an air-breathing frog, the following changes occur: As the gills disappear the afferent and the efferent arteries unite. The first branchial artery on each side loses its connection with the dorsal aorta and passes forward into the head, being known as the *carotid artery*. The second pair remains conservative; that is, each passes up around the intestine and the two unite to form the dorsal aorta. This pair is known as the *systemics*. The third pair degenerates. The fourth pair bud off a branch on each side which grows out to the lung. Its connection with the dorsal aorta degenerates, so that the fourth branchial arch is converted into the pulmonary arteries. The above changes are a good illustration of change of function in which structures formerly used for one purpose are modified for other uses due to a different mode of life. Many instances of such modifications of organs can be found both in Animals and Plants. The general condition of the aortic arches of reptiles is much the same as that just described for Amphibia. But it is very interesting to know that the embryo reptile first possesses rudimentary arches similar to that of fish though of course there are no gills. A modification is found in Birds and Mammals. The main arteries from the heart are much the same as in Amphibians and Reptiles with some important differences. In Birds, the carotid arteries have shifted and originate from a branch of the aorta. This same branch also supplies branches to the breast and wings. In the frog, arteries similar to the last arose from the systemic. In Birds, only the right branch of the systemic pair of the frog remains as the feeder to the dorsal aorta; it is very large and is known as the *aorta*. It arises from the left ventricle.

There is no sign of the third. The fourth or pulmonary pair originate from the right ventricle.

The condition in Mammals is similar to that in Birds, with this curious difference. The great aorta as it originates from the left ventricle is the left branch of the systemic pair of the Amphibia and Reptiles, instead of the right as in Birds. In Birds, the great aorta turns from the heart over to the right side of the body. In Mammals, it curves over to the left and then around to the backbone. Still more remarkable is the fact that in the embryos of these forms (Birds and Mammals) the early history of the vessels from the heart is fish-like, then amphibian-like, and then bird- or mammal-like. Even more remarkable is another observation. It was stated that in metamorphosis of the frog the fourth aortic arch buds off the pulmonary. For some time this artery, however, continues a connection with the dorsal aorta, but this connection later degenerates as the gill degenerates. Curiously enough, this same procedure is gone through in the embryonic development of the pulmonary artery of higher forms, like Mammals. In the vast majority of cases, the connection between this fourth arch and the dorsal aorta degenerates long before birth. But in *some* cases it fails to do so and persists in the adult condition after birth. This queer anomaly of great historical interest is known in human anatomy as the "*Ductus Botalli*" for it occurs, though very rarely, in human beings, indicating that *men are "animals"* in the biological sense.

4. Excretory Systems.—Protozoa, Porifera, and Coelenterates have no special excretory systems. Excreta are probably discharged from the free surfaces of the cells. In the flatworm, there is a complicated system of tubes joining longitudinal canals which discharge wastes to the outside. Within the body the branching tubes terminate in flame cells. These are large cells with irregular branches and contain a blind duct at the end of which is a mass of cilia. Wastes collect in contractile vacuoles in the protoplasm of the cell and are discharged into the lumen of the cell, from which they are driven forth by the cilia into the tubes.

In the earthworm (Annelid) there are pairs of serially

repeated nephridia. These are coiled tubes. They open internally into the coelomic cavity surrounded by coelomic fluid. The cilia at the mouths of these openings drive a current into the nephridium. The tubular part of the nephridium is invested in a capillary network. The cells of the nephridium absorb wastes from the blood, and discharge these wastes into the lumen of the tubule and hence to the outside. Cilia lining the tubule assist in the expulsion.

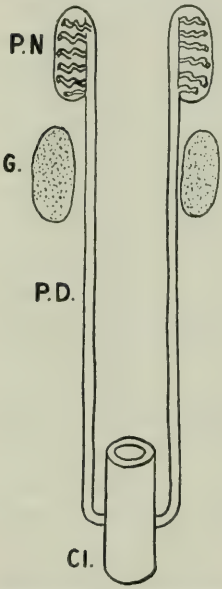

FIG. 284.—DIAGRAM OF VERTEBRATE PRONEPHROS.

P. N., Pronephros; *G.*, Gonad; *P. D.*, Pronephric duct; *Cl.*, Cloaca. Sex cells pass from gonad into coelome and out through pores in abdominal wall.

In Amphioxus a somewhat similar condition is found. In vertebrate embryos there appears a *Pronephros* or head kidney (Fig. 284). This consists of a series of segmentally arranged tubules each opening into the body cavity at one end. The outer ends, however, do not open to the outside of the body but are connected to a conducting tubule or segmental or pronephric duct which connects posteriorly with the cloaca. In Cyclostomes it remains throughout life somewhat degenerated. In some Fish and Amphibia it is found in early stages.

Later in the embryo of Fish and Amphibia a second set of nephridial tubules develops toward the posterior end of the animal. As this group of tubules develops the first group (Pronephros) degenerates. The second kidney is called the *Mesonephros* (Fig. 285). At the same time the pronephric duct splits lengthwise into two. One of these remains the ureter and the mesonephric tubules discharge into it. The other duct becomes the oviduct in the female. Each of these oviducts is funnel-shaped at the anterior end but opens into the cloaca at the posterior end. This new kidney is also called the *Wolffian body*, and the ureter tube is called the *Wolffian duct*, while the oviduct tube is called the

Müllerian duct. A curious condition prevails in male animals that possess a Mesonephros, in that the Müllerian duct often persists as a blind rudimentary tube. From the testes fine tubes, called the *vasa efferentia*, grow out connecting the testis with the *Wolffian duct*, which serves in the male as a sperm duct during the breeding season. During the remainder of the year it is only a ureter. The Mesonephros or Wolffian body is the functional kidney of Fishes and Amphibia. The adult kidney is not merely a few segmentally repeated nephridial tubules. It is a compact organ consisting of a very great many tubules, all joining larger branch ducts which in turn empty into the ureter.

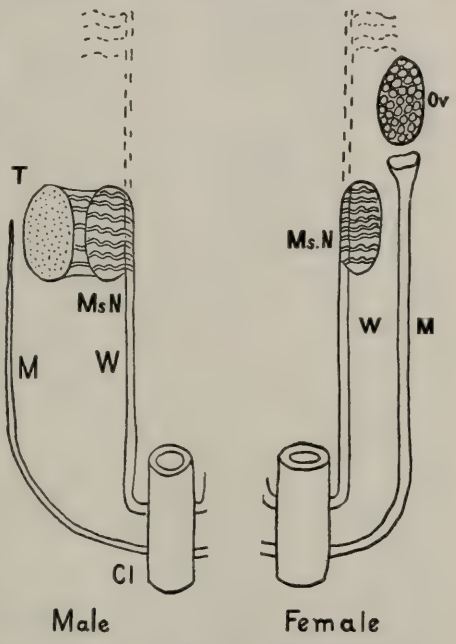

FIG. 285.—DIAGRAM OF MESONEPHRIC SYSTEM OF FISH AND AMPHIBIA.

Dotted lines—degenerated pronephros; *MsN.*, Mesonephros; *T.*, Testis (male gonad); *W.*, Wolffian duct (Ureter); *M.*, Rudimentary Müllerian duct (Oviduct) in male—Functional oviduct in female; *Ov.*, Ovary.

In Reptile, Bird, and Mammal embryos, the pronephros first appears, then as it degenerates the mesonephros appears. (Fig. 286.) Then a new third kidney appears, namely the *Metanephros*. It is posterior to the mesonephros. Moreover, it develops a new discharging tube—Ureter. In the meantime, the Mesonephros gradually disappears. The Metanephros remains as the functional adult kidney of Reptiles, Birds, and Mammals. The Müllerian duct of the mesonephric system persists, however, as the functional oviduct of females. The vasa efferentia of the testis pass into the *Wolffian duct*, which now performs the exclusive

duty of a sperm duct or *vasa deferens*. In early embryonic nephridial tubules, the outer ends open by ciliated funnels into the body cavity. This end is the nephridial mouth or *nephrostome*. In the mesonephros, a small cup-shaped cavity develops near the nephrostome. This becomes filled with capillaries, and is known as *Malpighian body*. Indications of nephrostomes are still present in the frog's kidney. They appear on the surface as pits. But they disappear entirely in the metanephros. In this kidney the tubules are supplied entirely by the blood and terminate in Malpighian bodies. Suprarenal bodies (ductless glands) are found near the kidneys or gonads of Vertebrates.

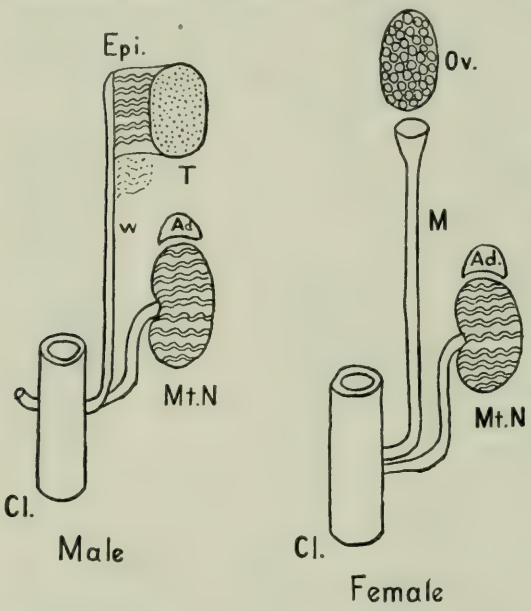

FIG. 286.—METANEPHRIC SYSTEM IN REPTILES, BIRDS AND MAMMALS.

Mt.N., Metanephros with its own metanephric duct, or functional ureter; *T.*, Testis; *Epi.*, Epididymis; *Ad.*, Adrenal (suprarenal in man) gland; *Ov.*, Ovary; *M.*, Müllerian duct; *Cl.*, Cloaca. W., Sperm duct.

II. ORGANS OF ADJUSTMENT

Notwithstanding the fact that the organism is a complete whole whose parts are interdependent, the foregoing systems of organs are concerned in keeping the cells supplied with material and in removing wastes. Life is one continual process of adjustment to varying environmental conditions. Moreover, food and security from pos-

sible enemies must be obtained. Certain systems of organs seem to be concerned with this part of life. They are the *sensory*, *nervous*, and *muscular* systems. Locomotion in higher forms like insects, and vertebrates, is often rapid, sustained, covering large distances and consuming much energy. In these cases muscles are associated with skeletons. Moreover, the surface of the body is covered with skin that protects internal organs and also affords a location for sensory organs. In discussing organs of adjustment skin and skeleton should be included.

Skin or External Covering.—In some Protozoa, the external superficial protoplasm is more dense than that inside and from it may extend cilia or flagella. In Sponges there is an outer covering layer. In Coelenterates the ectoderm is covered with a non-cellular thin coat,—the cuticle. In Flatworms there is a somewhat similar but firm cuticle and in some parasitic Roundworms it is somewhat thickened and hard. In Annelids it is thin, as in the active earthworm. In Vertebrates it rises to the dignity of a special complicated covering composed of two main layers: (*a*) *Epidermis* formed of several layers of cells most of which are dead and "horny" called—the stratum corneum, derived from a deeper living germinating layer the *stratum germinativum*. The epidermis contains no blood vessels or nerves. Below it is (*b*) the *Dermis* or lower skin. This is special connective tissue with blood vessels and nerves. The epidermis is nourished by these. From the epidermis are derived some types of scales and feathers and hairs. From the dermis is derived the scales of most fish, bony plates of crocodilia, and of such Mammals as the armadillo and some of the bones of the skull. The teeth of Vertebrates are also largely dermal in origin. The skin contains important sense organs; of touch, pain, and temperature. It contains sweat and oil glands. Mammary glands are skin glands.

Skeleton.—A supporting framework of a sort occurs in radiolarian Protozoa and the highest Mammals, although many intervening forms lack it. In Arthropods there is a horny or chitinous outside skeleton somewhat analogous to

the armor of old-time knights. To the inner surface of these parts are attached muscles which connect adjoining parts. In Vertebrates there is an endoskeleton of cartilage

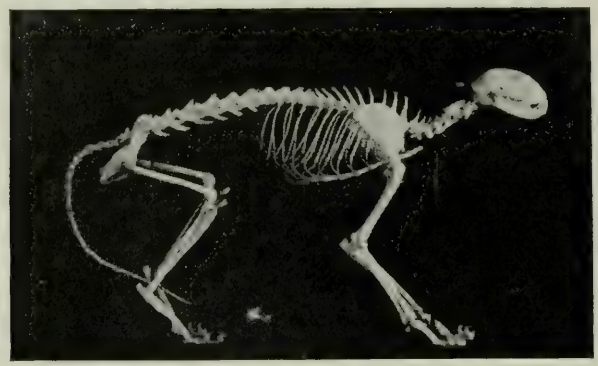

FIG. 287.—SKELETON OF CAT—PHOTOGRAPH.

Note axial skeleton composed of skull and spinal column. The appendicular skeleton—the limbs and girdles. In anterior appendage note scapula, humerus, radius, ulna, etc. In posterior limb—note ilium, ischium, pubis femur, tibia, fibula, etc. (Photo by Author.)

in lower forms; and of cartilage and bone in such intermediate forms as Amphibia, but almost entirely of bone in Birds and Mammals.

The skeleton (Fig. 287) consists of an *axial* and an *appendicular* part. The axial skeleton consists of the skull and verte-

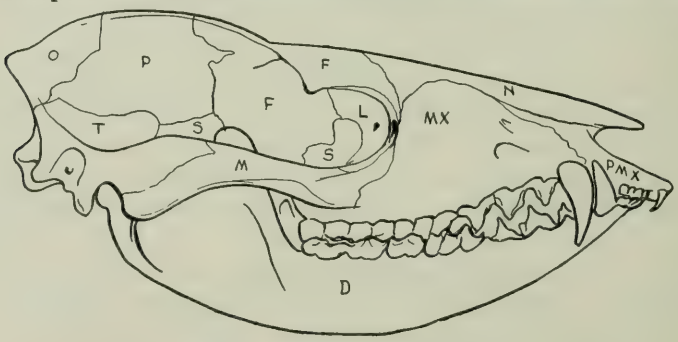

FIG. 288.—SKULL OF OPOSSUM.

Side view—*O.*, Occipital bone; *P.*, Parietal; *F.*, Frontal; *L.*, Lachrymal; *Mx.*, Maxillary; *PMX.*, Premaxillary; *N.*, Nasal; *S.*, Sphenoid; *T.*, Temporal; *M.*, Malar; *D.*, Dentary.

bral column. The appendicular part consists of the front limbs and pectoral girdle, and the hind limbs and pelvic girdle.

The Mammalian skull consists of the *cranium* and *face*

(Fig. 288). The cranium encloses the brain while the face forms the nostrils, mouth, jaws, etc. Some of the bones of the cranium frequently found are frontals, parietals, occipital, temporals, ethmoid and sphenoid. The face is formed by the nasals, lachrymals, malars, palatals, maxillaries, pre-maxillaries and vomers. The lower jaw is the dentary or mandibular. There is considerable variation in the bones of the skull, but the similarity is as notable as the differences.

The vertebral column, the backbone of the Vertebrate, is composed of vertebrae. A vertebra (Fig. 289) possesses a supporting centrum, the neural arch enclosing the spinal cord, the neural spine to which some muscles of the back are attached and transverse processes to which ribs may be attached. Five kinds of vertebrae are found in Mammals, all modifications of a generalized type, namely *cervical*, forming the neck, *thoracic*, which may have ribs, *lumbar* and *sacral*, to which the pelvic girdle is joined, and *caudal* or tail vertebrae. Ribs may be lacking or there may be many. They are present wherever needed to support the walls of the trunk.

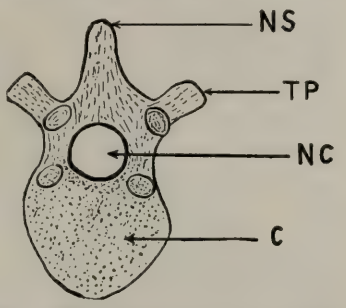

FIG. 289.—DIAGRAM OF A VERTEBRA.

N. S., Neural spine; *T. P.*, Transverse process; *N. C.*, Neural canal; *C.*, Centrum.

There is also similarity between the anterior and posterior appendages (Fig. 290). In the first place both pectoral and pelvic girdles consist of three parts—a *dorsal element*, the *scapula* in the pectoral girdle, and the *ilium* in the pelvic girdle. The scapula is joined indirectly by ligaments and muscles to the axial skeleton, while the ilium is firmly united directly to sacral vertebrae. Each girdle has two processes extending ventrally. In the pectoral girdle, the *procoracoid*, and in the pelvic, the *pubis* extends down and forward while in the pectoral the *coracoid* and in the pelvic, the *ischium* extends down and backwards. The procoracoid is represented by cartilage and it is replaced in higher forms by a bony clavicle.

The forelimb consists of a *humerus* joined to the pec-

toral girdle where its three parts meet, next of a *radius* and *ulna* forming the forearm, then of eight carpal or wrist bones, of five *metacarpal* or hand bones, and five fingers or *digits*, each composed of several phalanges. The hind limb consists of a *femur* or thigh joined to the pelvic girdle where its three bones meet, then the *tibia* and *fibula* or leg, the eight *tarsal* or ankle bones, five *metatarsals* or foot bones, and five toes each composed of phalanges. In forms above Fishes, this limb plan prevails, although there are all sorts of modifications of it. For example, radius and ulna are often fused. The fibula may be reduced to a rudiment. The greatest variation is in the digits and in hands and feet; as in the feet of cows and horses and wing of the bird. In man the coracoid is a mere knob attached to the scapula.

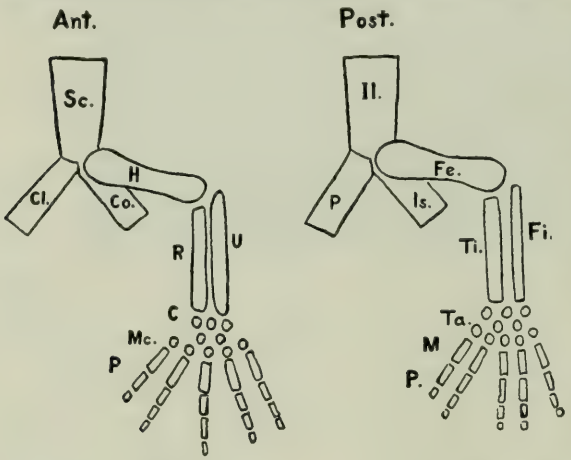

FIG. 290.—PLAN OF CONSTRUCTION OF APPENDICULAR SKELETON OF AMPHIBIA, REPTILES, BIRD, MAMMALS.

Ant., Anterior; *Post.*, Posterior; *Sc.*, Scapula; *Il.*, Ilium; *Cl.*, Clavicle; *P.*, Pubis; *Co.*, Coracoid; *Is.*, Ischium; *H.*, Humerus; *Fe.*, Femur; *R.*, Radius; *Ti.*, Tibia; *U.*, Ulna; *Fi.*, Fibula; *C.*, Carpals; *Ta.*, Tarsals; *M.*, Metacarpals and metatarsals; *P.*, Phalanges.

Muscles.—The skull protects the brain, and the backbone and ribs protect visceral organs. But more than this, the backbone is a rigid axis to which levers are attached. These levers are moved by skeletal muscles in limbed forms for use in locomotion. In the tubular earthworm's body wall and likewise in its intestine there are longitudinal and circular muscles. Contraction of the longitudinal muscles at any point shortens this tube, contraction of the circular muscles decreases the caliber of the tube. A combination

of these two types of contraction passing like a wave along a tube would have the effect of forcing along in front of the moving constriction any contents present. This type of contraction is very universal in animals. It is known as *peristalsis*. It is the common movement of intestines, of oviducts, of ureters, and arteries.

The amphioxus body wall possesses a series of segmentally repeated muscle masses or *myotomes*. These are seen also in Fishes and in lower Amphibia and in the embryos of higher forms. They are more primitive in forms without limbs. Their contraction on one side and relaxation on the other moves the body sidewise as in the movements of the tail in swimming. When limbs are introduced, the segmentally arranged myotomes in the neighborhood of the limbs grow out to the girdle and limb bones thus modifying the myotomes in that neighborhood. With the increasing modifications in the limbs and with changes in their use, the modifications in the muscles become more complex. The fore and hind limbs of Necturus are small and quite similar, and the muscle supply of each is similar. In the frog there are short weak front limbs and large strong hind limbs. The muscle outfit of each is extremely different. The muscle system of the front limb and hind limb of a bird are very different. One does not find any close similarity between the musculature of the front limbs of a dog, horse, bat or chimpanzee. Muscles are plastic structures, far more plastic than bone, and to the comparative anatomist even bone is not regarded as unchangeable. All structures are but clay in the " hands " of the great sculpturing forces of adaptation. In spite of the extreme modifications of muscles in different types, the trained myologist is satisfied as to a simple general underlying plan of similarly repeated myotomes. Skeletal muscles usually have a contractile portion called the *belly* and two ends terminating in inelastic *tendons* whereby they are attached to bones. The muscle has a proximal end attached to some part toward the central axis. This is the *origin* of the muscle. The outer distal end is the *insertion*. The origin is usually fastened to a support, and the muscle lifts a lever

to which it is inserted. Motor nerves end in muscles. A *motor impulse* passes out from a central nerve organ to the end plate of the nerve in the muscle and causes the muscle to contract. Skeletal muscles are under the control of the will, i.e., voluntary, but the muscle of the heart and intestines is involuntary.

Nervous System.—First indications of a nervous system were seen in Coelenterates. Nerves are present in all higher forms. Annelids show a centralized nervous system with ventral nerve cord, segmental ganglia, dorsal brain, and peripheral nerves. Arthropoda with their condensed bodies show a concentration of this same general plan in the large thoracic ganglia. The nervous system reaches its highest development in the Vertebrates where it is organized into (*a*) *Central nervous system* of brain and spinal cord, (*b*) *peripheral system* of cranial and spinal nerves and (*c*) *sympathetic system.* Descriptions of these in the study of the frog should be read again here. In the study of the Vertebrates a general increase in the size and the importance of the cerebral hemispheres is seen as we pass from Fishes to Mammals (Fig. 291) culminating in the human brain where it is relatively enormous and richly fissured and convoluted, thus making the *cortex* (or rind) of greater area than the cranial space it occupies. The olfactory lobes and optic lobes decrease relatively in size and importance, while the increase in the cerebellum is secondary only to that of the cerebrum. Between the cerebral hemispheres and optic lobes is the between-brain or *diencephalon.* Projecting from this on the ventral side toward the roof of the mouth is an outgrowth. Here is attached an important ductless gland, the *pituitary.* Also from the dorsal surface a stalk-like structure extends upward, known as the *pineal gland.* In some lizard-like forms this terminates in the roof of the skull in a sensory structure sensitive to light, on account of which it is sometimes called the pineal or third eye.

Nervous systems of animals are orderly organizations of nerve cells whose primary function is to carry impulses. On the whole, the nervous system acts as a middleman between the surface of the body where changes in the

external world rouse *sense organs* to action, and the *muscles* which make the proper adjustments to these external changes. Analysis of the nervous system shows that it is composed of complex cells of varying shapes called *neurons*. These have long thread-like processes admirably adapted for carrying impulses. Proper connections and organizations of these make possible the carrying out of all adaptations. Operations of internal body organs are carried out with the help of the sympathetic system.

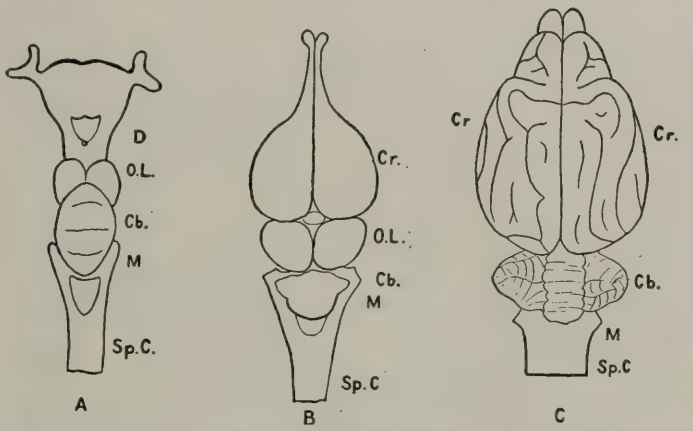

FIG. 291.—DORSAL VIEW OF BRAIN OF DOGFISH, LEFT; ALLIGATOR, MIDDLE; DOG, RIGHT.

Cr., Cerebrum; *D.*, Diencephalon; *O. L.*, Optic lobes; *Cb.*, Cerebellum; *M.*, Medulla; *Sp. C.*, Spinal cord. (From Ziegler Models.)

In all Vertebrates the five parts of the brain are plainly discernible. The cranial nerves of all are surprisingly uniform, as is the case with the spinal cord and spinal nerves.

Sense Organs.—Sense organs developed from ectoderm are cellular structures whose function it is to be *irritated* by sudden changes in the external medium. A stimulus is a sudden considerable change in light, sound, touch, temperature, or chemical environment. A very slow increase or decrease in intensity of any of these would probably not awaken to activity or stimulate a sense organ.

References to the sensory organs of lower groups have been made. The earthworm does not have any special

sense organs of touch, smell, or sight and yet is sensitive to all these types of stimuli. Probably insects react to ranges of stimuli beyond our knowledge. Arthropods and Molluscs have well-developed sense organs. The sense of direction of Birds is possibly due to the possession of powers, resident in their sense organs or brain, which we do not possess. The sense organ of smell consists of cells located in membranes in the nose. These cells are connected by nerves to the brain. There are only nasal sacs in Fishes while in higher forms they open by passageways into the mouth and take on a double function, assisting also in respiration. The odor stimulus is carried to the sensory surface with the air or water taken in. The skin contains many sensory organs of touch, pressure, and temperature. In some cases layers of cells surround sensory nerve endings to form those organs. Sensory organs occur in muscles and are stimulated when the muscle changes its form, thus giving an idea of muscular motion. Cells formed into organs and stimulated by certain substances in food and drink occur near the surface of the tongue forming sense organs of taste.

The ear develops as a pit in the ectoderm. Ears like this are found in Invertebrates. In the Vertebrates (Fig. 292) this pit becomes detached from the surface and forms the internal ear within the bone of the skull. Inside of the skeletal surroundings it occurs as a membranous sac filled with liquid and becomes very complicated. It forms two sacs known as the *sacculus* and *utriculus*. From the sacculus develops, in higher forms, the spirally tapering cochlea containing sensory cells stimulated indirectly by sound waves outside the body. The sensory cells of the cochlea are connected by certain fibers of the eighth cranial nerve to the brain. From the utriculus there develops the semicircular canals. One of these is horizontal, the other two are vertical and at about a right angle to the first and to each other. These canals are membranous tubes and each contains an enlargement called an *ampulla* where are the sensory cells which are stimulated by changes in the position of the head (or body). Information borne to the brain from these sense organs over other fibers of the eighth

nerve, gives the animal knowledge of its special position. The cochlea is the sense organ of hearing and the semicircular canals of equilibrium. As long as animals are immersed in water sound is of minor importance, but not so in the case of equilibrium. Impulses to the ear of fishes must come through the skull.

The old spiracular cleft of Elasmobranchs became the tympanic cavity or middle ear between the surface of the skull and the inner ear of land forms. The Eustachian tube

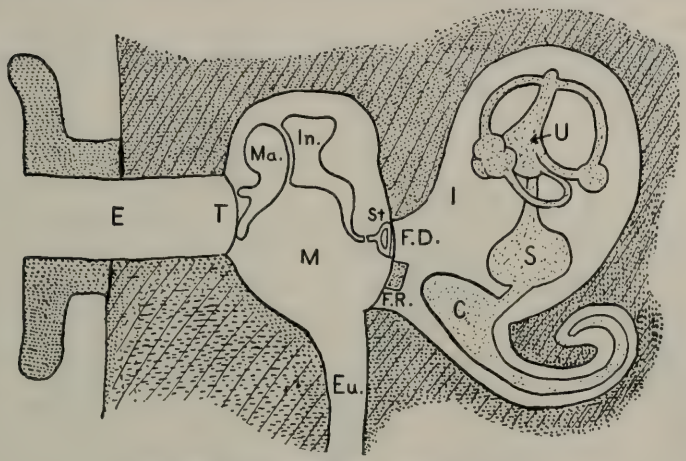

FIG. 292.—DIAGRAM OF MAMMALIAN EAR.

E., External passage (meatus); *T.*, Tympanum; *Ma.*, Malleus; *In.*, Incus; *St.*, Stapes; *M.*, Mid-ear; *Eu.*, Eustachian tube; *F. O.*, Fenestra ovalis; *F. R.*, Fenestra rotunda; *I.*, Inner ear; *U.*, Utriculus; with its semicircular canals; *S.*, Sacculus to which is attached the cochlea; *C.*, Sensory cells of hearing are in the cochlea. Sensory cells of equilibrium are in the ampullae of semicircular canals.

from the mouth to the mid-ear is a part of it. Between the inner and the middle ear a little window, *fenestra ovalis*, develops. Stretched across the external opening of the middle ear is the ear drum or tympanic membrane. This is flush with the surface of the head in Amphibia. In higher forms it lies at the inner end of a small passageway—the external canal. Surrounding it, in many Mammals, is the external ear. Stretching across the middle ear from tympanum to fenestra ovalis in Amphibia,

Reptiles and Birds is a single little bone, the *columella*. Sound waves in air vibrate the tympanum. These vibrations are conveyed by the columella to the inner ear drum stretched across the fenestra ovalis. Vibrations in this set up vibrations in the liquid in the cochlea which stimulate the sensory cells of hearing. In Mammals, the columella is replaced by a chain of three little levers, *outer, malleus; middle, incus; inner, stapes*, by which the vibrations are more effectively transmitted. These structures are special modifications of parts used for other purposes in lower Vertebrates.

Sight.—Special sense organs of vision appear as animals become more specialized. The eye of all Vertebrates is surprisingly similar in structure. In cave animals and deep sea forms, it is degenerate. The eye is a hollow globe or rather parts of two globes (Fig. 293). The wall is of tough resistant material. This is the outer sclerotic coat, or the white of the eye. It has a transparent front, known as the *cornea*. Inside the sclerotic is the vascular and pigmented choroid coat. In front it does not lie close to the cornea but close to the front of the lens and contains an aperture, the *pupil*. The disc around the pupil is called the *iris*. The third or inner coat of the eyeball is the *retina* (Fig. 294) which contains the special sensory cells of vision. These are connected by a

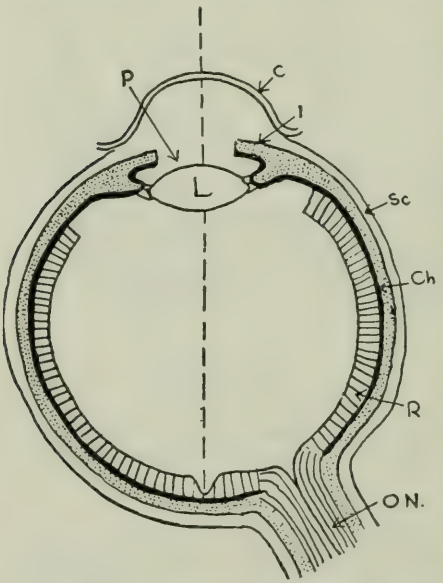

FIG. 293.—DIAGRAM OF VERTEBRATE EYE.

C., Cornea; *P.*, Pupil; *I.*, Iris; *L.*, Lens; *Sc.*, Sclerotic coat; *Ch.*, Choroid coat; *R.*, Retina; *O. N.*, Optic Nerve. The depression at end of dotted line is point of most distinct vision.

chain of nerve cells to the brain by the optic nerve. The lens is located just behind the iris and is biconvex and transparent. It is held in place to the choroid coat by the suspensory ligament and, unlike a camera lens, its convexity can be changed and so adjust the eye to different focal distances automatically. Between the lens and cornea is fluid aqueous humor and behind the lens is the thicker vitreous humor. Light waves reflected from external objects pass through the lens forming images and stimulate sensory cells in the retina behind it. Impulses are carried over the optic nerve to the brain.

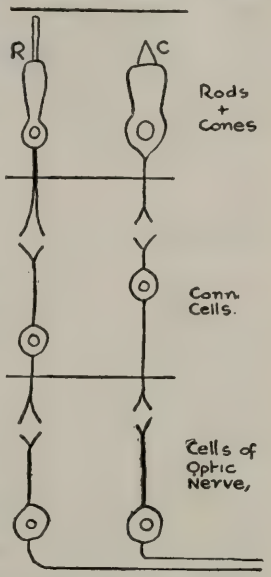

FIG. 294.—DIAGRAM OF ARRANGEMENT OF CELLS IN RETINA.

Rods and cones (sensory cells) are back against pigment; outside is layer of connecting cells, and cells of optic nerve toward the light.

The eye is moved by six muscles in each eye which raise the eyes, lower them, turn them to the left, to the right or roll them. Usually these muscles work harmoniously. It is not necessary to dissect a human eye to get a general idea of its structure. The eye of the ox or the dogfish will give about the same information. In land Vertebrates, lachrymal glands near the eye keep the eyeball moist and clean with their secretions.

Pain.—There are also undoubtedly special sense organs of pain located in the skin. These may also be present in internal organs such as the viscera. Operations involving the removal of tumors from the brain reveal the fact that the patient feels no pain, thus indicating that the brain has no pain nerves.

Summary.—Muscle, nerve, and sensory systems, as shown in Vertebrates, are elaborate developments of what seem to be simple conditions in Protozoa. There it was stated that the protoplasm was irritable, conductive and contractile. In the higher forms, multicellular and effective sen-

sory, nervous, and skeleto-muscular systems appear to carry out their primary purpose of constant adjustment and readjustment to this everchanging world. Moreover, the animal is not passive like the plant. There is an unceasing process of adjustment. It is easy to study lifeless organisms, but that is only a part of Biology. The living organism constantly adjusts and readjusts.

III. Methods and Organs of Reproduction in Animals

Reproduction in plants is chiefly an alternation between *sexual* and *asexual* generations. They also reproduce by *fission*, by *spores*, by *buds* and by *cuttings* involving regeneration. On the whole, all of these methods are employed by animals, but the prevailing method of reproduction in higher animals is sexual.

Fission.—In this case the body of the mother cell divides into two daughter cells each of which grows to maturity when the process is repeated. The parent animal of course disappears. The new and mature daughters are new animals. Fission occurs in Protozoa. New generations of Protozoa occur from sixteen to twenty-four hours apart. Some worms at times automatically cut themselves in two and a new worm develops from each piece.

Sporulation.—This is common in the Sporozoa, but is only part of the life cycle. A Sporozoan encysts, i.e., the cell wall forms a hard, thick wall. The nucleus and cytoplasm divide and subdivide many times forming many small cells, sporozoites, which enter cells of the intestine and by multiple fission, or sporulation, form male and female gametes which, on fusing, form a cell (*zygote*) which in time will produce sporozoites again. The life cycle of parasitic flatworms involves something akin to sporulation.

Budding.—The bud is a small outgrowth of protoplasm which grows into a form like the parent. It early separates from the parent and leads a free life as illustrated by young Hydras. Budding rarely occurs in Protozoa. It is more common in some other Invertebrates. The

Hydroids, like Obelia, are formed in this way; so are Corals and the Medusoids of hydroid colonies. Some worms indeed, reproduce by budding. The process is present also in the Tunicate group of the Chordata. Sometimes internal buds are formed. This is found in fresh-water sponges and some higher forms allied with the Annelids.

Parthenogenesis.—This is a type of reproduction in which eggs develop without fertilization. (See sexual reproduction.) Asexual reproduction does not occur in the Nemathelminthes, Echinodermata, Mollusca, Arthropoda or Vertebrata. It is more usual among lower forms.

Sexual Reproduction.—In sexual reproduction the new individual develops from a single cell (*zygote*) formed by the fusion of two gamete cells. If of the same size they are called *isogametes;* when of different sizes, *heterogametes*, in which case one is smaller and more active, called a *microgamete* in Protozoa, sperm or *spermatozoa* in Metazoa; the other gamete is larger and passive and is called a megagamete in Protozoa, egg or *Ovum* in Metazoa. In flagellate Protozoa, the Mastigophora, are found cases of fusion (or fertilization) of isogametes or heterogametes. Many instances of union between microgametes and megagametes are found in Sporozoa.

In the Infusoria occurs a specialized form of sexual reproduction. Two Paramoecia come together, i.e., *conjugate*. The macronucleus of each degenerates. The micronuclei, however, divide a number of times and most of the resulting portions degenerate. Two, however, remain in each Paramoecium, one of which passes over into the other animal. The two micronuclei then fuse and the animals separate and, after certain fissions, form Paramoecia each with a micronucleus and macronucleus. It has long been maintained that conjugation and sexual reproduction in Protozoa renews the youth of animals that have become senile through repeated reproduction by fission. Experiments by Woodruff in which Paramoecia reproduced by fission at least daily for fourteen years when surrounded by a favorable environment (food, etc.), indicate that although rejuvenation may be an effect of conjugation yet it is not vitally necessary. It also

indicates that this is not the fundamental reason for sexual reproduction. However endomixis did occur.

In Metazoan animals, sperm and eggs are called *germ cells*. These are produced by special glands called *gonads*, the ovary of the female producing eggs and the testis of the male, producing sperm. These glands are set apart from all the other organs to produce eggs and sperm. The germ cells take no part in carrying out the functions of metabolism or adjustment of the organism as a whole. And yet the gonads are constantly in vital relation to all other organs and metabolism and adjustment of a sort must occur in them. The blood which flows through other organs flows through them. Formation of the protoplasm of new germ cells comes from substances furnished by the blood. Sperm and eggs are in a sense generalized cells—different from the special cells which compose the other parts of the body such as nerve and muscle cells. United they alone have the power to form a new individual.

There are some exceptions to this rule. Drone bees develop from unfertilized eggs laid by the queen. In the Aphids, females develop from unfertilized eggs. This type of reproduction is known as *parthenogenesis*, i.e., generation of a new individual from part of the parent. Its relation to budding is obvious.

Artificial parthenogenesis is the experimental production of certain animals from their eggs alone and without sperm, although they normally reproduce from eggs and sperm. The eggs are treated with various physical and chemical agents such as immersion in concentrated or diluted sea water for a short time or with chloroform, ether, alcohol, toluol, saponin, salts, or bases, and also by shaking the eggs or pricking them.

Alternation of generations is not the rule but occurs here and there among animals. It occurs among the Sporozoa, Hydroids, Flatworms, possibly among a few marine Annelids and in some Insects. For example, most insects which are parthenogenetic interpolate a bisexual phase at some time. The female Aphids produce female broods all summer parthenogenetically. In the fall males and females appear.

These males fertilize the eggs of females. The eggs have hard shells which resist the cold of winter. From them females alone are hatched out in the spring. These produce parthenogenetically until fall again.

Paedogenesis.—In certain animals the immature and undeveloped can reproduce sexually. Thus in a certain fly, Miastor, ova develop larvae, parthenogenetically. The larvae escape from the parent and reproduce in a similar fashion. After several generations the larvae pupate, and reproduce sexually as adults. The Axolotl, an Amphibian, has been known to reproduce sexually in the larval stage if prevented from maturing on land. The adult form is Amblystoma. Paedogenesis, Parthenogenesis, and Sporulation exemplify a tremendous production of offspring which ensures the continuance of the species even though the chances of survival are limited.

The question arises as to why sex arose when reproduction can take place without it. Suffice it to say here that sexual reproduction ensures variation in new individuals. The chances are that the protoplasm of any sperm is not the same as that of the egg and so in sexual reproduction there is the combination of different protoplasms. The resulting individual is new. No other exactly similar individual ever existed before. The importance of variation is indicated in the discussion of Heredity.

Reproductive Organs.—The establishment of special cells (sex cells) occurs very early in animal forms. It appears in Volvox even before there are any special organs for metabolism or adjustment. It is also known in some cases that *very early* in embryonic history certain cells are set aside to form sex glands. These facts indicate that the function of reproduction is deep-seated and fundamental, that the continuance of the species is as important as is breathing, digestion and locomotion to the individual. Animals live to reproduce. While sex glands (ovary and testis) are usually present in multicellular animals, yet special ducts for conveying their products from the animal are not always necessary and may be absent. For example, in Hydra simple sex organs are found on the surface of the body and

sperm escape directly from the testis into the sea water. In the jelly fish, on the other hand, sex glands occur in the walls of the gastro-vascular cavity and sperm and eggs pass into this cavity and thence out. Goniducts of one kind or another for conveyance of sperm and eggs, are found in Flatworms, Roundworms, Annelids, Molluscs, Arthropods, and Vertebrates. In some animals, the gonads grow and become functional only during that period of the year when conditions are most favorable for breeding.

Both types of sex glands often appear in the same animal. Such an animal is called *monoecious*, or *hermaphrodite*. Hermaphroditism is more often the rule than not in the lower animals. For example, it is noted in Volvox, Sponges, Coelenterates, Flatworms, Roundworms, and Annelids. It continues to be present in other groups, although it is rare in the higher Vertebrates. Sometimes the same gland normally functions as a testis and ovary, that is, the animal possesses an hermaphroditic gonad. This is the case in certain land snails. Riddle has recently described a remarkable phenomenon which he observed in a ring-dove, born a female. It laid eggs. Later its ovary became diseased and degenerated but regenerated a testis.

Self-fertilization, or physiological hermaphroditism, is more rare than anatomical hermaphroditism. The monoecious animal usually first functions as a male then later as a female or vice versa. Most Tunicates first produce eggs and then when this period passes, their testes become functional and they produce sperm. In the hag-fish, Myxine, the animal first produces sperm then later eggs. In this way the eggs from any one animal are not likely to be fertilized by the sperm from that animal. It has been found that many successful plants are normally self-fertilizing. There is strong evidence to indicate that hermaphroditism was the primitive condition but that animals of separate sexes become the rule in higher forms. These are called dioecious.

Eggs and sperm must reach the outside of the animal. As long as the gonads are located where their products

may easily reach the exterior, no special outlets are necessary. Where the gonads are developed from tissues lining the body cavity, their products (eggs and sperm) are first discharged into the body cavity, and then escape. They must be discharged from this by one kind of duct or another. In many female Teleosts the ovary lies in a sac which extends to the cloaca. In Cyclostomes the eggs and sperm pass into the body cavity and from this through pores into the cloaca.

Usually ducts associated in one way or another with excretion are used. But why excretory ducts? In one sense, eggs and sperm are excretions, not fluid it is true, but cellular excretions. The oviduct in Vertebrates originated as a separation from a primitive ureter. In males, the sperm duct, though primarily a ureter in Fishes and Amphibia, became connected with the testis and served a double purpose. In the Amniota (Reptiles, Birds and Mammals) it is no longer a ureter, but functions wholly as a vas deferens.

In lower forms, fertilization of eggs occurs normally outside the body. In aquatic animals—Coelenterates, Echinoderms, Fishes and Amphibia—eggs are discharged into the water and sperm are shed near them. In all cases there is a mutual attraction, between eggs and sperm. In land animals, eggs and sperm would easily be destroyed if exposed to the air for long, so sperm are introduced into the oviducts of the female. Internal fertilization is the rule in Elasmobranchs, which are more primitive than Teleosts in which fertilization is external. Internal fertilization is also the rule in Arthropods, Reptiles, Birds and Mammals. In most Elasmobranchs, in Reptiles, Birds, and Insects fertilized eggs are discharged from the body. Such animals are said to be *oviparous*. The eggs of Birds, Reptiles, Amphibia and Fishes have stored up in them considerable quantities of food. The yolk is formed in the ovary. The oviduct forms a surrounding mass of white or albumen and also shell membranes and a shell in Reptiles and Birds. The egg case of the skate is horny while those of turtle and hen are calcareous.

Many Vertebrates are *oviparous*, but some of these classes have representatives in which the young are developed within the body of the mother, i.e., are *viviparous*. Such cases are found among sharks, Teleosts, tailed Amphibia, and Reptiles. In all Mammals with the exception of the Monotremes, development occurs within the body of the mother. In the case of oviparity, yolk is produced by the ovary, but it is also true that in viviparous Mammals, the ovary is greatly concerned in developing the special system of foetal nourishment. The latter is a further modification of the form of yolk feeding. In both cases the embryo is kept more quiescent, which condition is more favorable for development and growth. The period of independent life is delayed and the period of greatest mortality is safely passed. The chance of survival is thus increased among the Placental Mammals by lactation and the care of offspring by the mother is of further benefit to the individual.

To secure the safe transfer of sperm to the oviducts of the female, organs of intromission appear such as the claspers of the male dogfish. Some such device is also found in certain Reptiles and Birds, and in the male mammal, it is the penis. The oviducts of Vertebrates remain separate tubes, terminating in the cloaca in Elasmobranchs, Amphibia, Reptiles and Birds and Monotreme Mammals. Examination and comparison of the higher mammals shows that beginning posteriorly, there is a fusion of the oviducts first to form a vaginal chamber for the reception of sperm and later a single uterus in which the eggs will develop. In Carnivora, the uterine portions of the oviducts are still separate and young develop in each horn. In the Primates, they have fused in this region into one common uterus or womb.

The essential fact in all types of reproduction in plants and animals is this, that a small mass of protoplasm separated from the body of one organism (in asexual reproduction) or formed from two (in sexual reproduction) has the power of developing into another organism like the parents. A sperm or egg of itself is incomplete. In sexual reproduction animals develop from a single cell. This single cell,

a complete whole, is present after the egg cell and sperm cell unite, and all the structures, organs, devices, secondary sex organs, sex antics of animals, and sex emotions of human beings are but part of the machinery concerned in bringing about the formation of a fertilized egg, union of egg and sperm. And for what? So that the race may continue! Race continuance is not primary, however, to the adult animal. As a rule, the first consideration of an animal seems to be self-preservation. Hunger and thirst are examples of primary feelings. But the reproductive instinct is closely allied to these for only a living animal can reproduce. Of the three great groups of functions comprising the physiological life, those of metabolism and adjustment are not only primary but pre-essential to reproduction. Many examples could be cited indicating that the third is the goal of the first two. Queen bees die when reproduction is over. Recall the case of the Mayflies, of the relation of ants and bees to the life of the colony; numberless instances are recorded of maternal sacrifices in attempt to preserve the life of offspring among many Vertebrates and especially the Mammals, so much so that these words, paraphrased from those of Tennyson, are indeed appropriate: "So careless of the individual, so careful of the type."

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CHAPTER XXIII

HISTOLOGY

Bichat, in his " General Anatomy " published in 1801, pointed out that not only were the structural relationships between animals true of their organs, but also of their tissues, such as muscle and nerves. In 1838–39, Schleiden and Schwann advanced this analysis when they announced the " Cell Theory " according to which, tissues (organs, etc.) are composed of cells. In 1858, Virchow (Fig. 295) extended the application of the Cell Theory to diseased tissues.

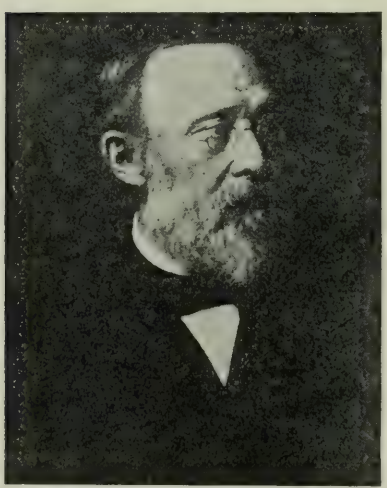

Fig. 295.—Virchow, pathologist. Author of "cellular pathology," 1858.

Multicellular Protozoa consist of permanent associations of many similar cells. In Volvox all the functions of metabolism and adjustment are carried on by each cell. Free single cells are found, it is true, in higher organizations. Examples are ameboid white-blood cells, red-blood cells, spermatozoa, and eggs. With the appearance of Metazoa there comes a division of labor and the appearance of separate forms of cells—each type performing a certain function better than other types. A simple illustration of this is seen in Coelenterates as in Hydra. Here are found two types of cells, *ectoderm* and *endoderm*. The former consists of oblong cells the general function of which is adjust-

ment. Endoderm cells are larger and their functions are those of metabolism. The appearance of physiological division of labor means the appearance of special cells or tissues—each having its own special morphological characteristics. This specialization of function in cells and tissues calls forth morphological dissimilarity in cells and tissues from a preceding earlier and simpler form. It is evident that physiological and morphological specialization has many advantages over the more primitive generalized condition.

Early embryos of Metazoa show ectoderm and endoderm. In the flatworm, not only is there ectoderm and endoderm tissue but between these a new tissue is developed, called *mesoderm*. This occurs between the outer ectoderm and the inner endoderm. It appears as a somewhat spongy tissue with many spaces in it. Later it is organized into muscle, into male and female gonads and ducts—and into excretory organs. *From the ectoderm is organized all nerve tissue.* Animals above the flatworm show a progressive building up of complex and special organs from ectoderm, endoderm, and mesoderm. The question is, to a considerable extent, embryological. A general idea of the histology of the higher animals is given here.

Tissues can be classified embryologically or physiologically. According to the latter method there are five kinds —*epithelial*, *connective*, *muscular*, *nervous* and *blood*.

1. Epithelial.—It is the most primitive. For example both ectoderm and endoderm of Hydra, etc., are epithelia. Epithelial cells show less degree of morphological departure from the shape of free cells. Epithelium covers and protects external and internal surfaces, canals, and tubes. Only hard external parts like teeth exist without epithelium. In simple conditions epithelium is only one cell deep. This type is found in all Invertebrates and in Amphioxus. In Vertebrates it occurs only internally. Secretions from the free surfaces of such cells form a non-cellular continuous layer called *cuticle*, as shown in the earthworm. In Insects it hardens into the chitinous exoskeleton and in molluscs into the calcareous shell. (Fig. 296.)

a. In *Columnar epithelium* the cells are column-like, a little longer than broad and located side by side. Their long axes are at right angles to the surface they cover. This type forms the lining of the intestine. The free end may possess a coating of cilia vibrating back and forth. This ciliated epithelium is common in Metazoa. It occurs in the trachea of Mammals for example. In some cases all the external epithelium is ciliated. The free end of the cells

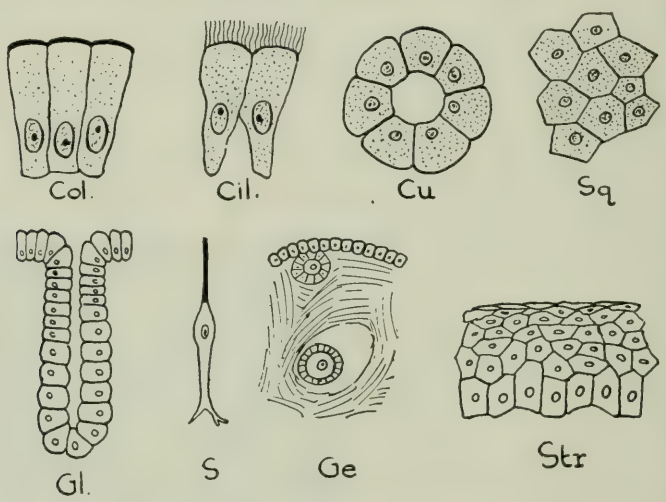

FIG. 296.—TYPES OF EPITHELIAL CELLS.

Col., Columnar; *Cil.*, Ciliated columnar; *Cu.*, Cubical; *Sq.*, Squamous; *Gl.*, Glandular; *S.*, Sensory; *Ge.*, Germinal; *Str.*, Stratified.

may possess collars and flagella, as is so characteristic of the Porifera and some Coelenterates. Short columnar cells are almost cuboidal in form and are well adapted to form the walls of ducts as in the urinary tubules of the kidney. Here they also function as glandular cells. The outer surface of sponges and the inner lining of the body cavity (*peritoneum*) and the blood vessels (*endothelium*) of higher animals consist of flat, scale-like cells—each connected with others at the edges—forming a very delicate membrane. This is called *squamous epithelium.*

b. Glandular epithelium forms the walls of glands. As a rule these have formed embryologically as outgrowths from embryonic columnar epithelia. These glandular epithelial cells absorb raw products from blood and elaborate these into characteristic compounds which they discharge from their free ends, which in many cases form a pocket or cavity connected with a duct formed of epithelium. Through this duct the secretion passes out. Often this type is associated with other tissues to form an organ like the liver or pancreas.

c. Sensory epithelium.—Some epithelial cells are specially modified to act as sense organs. These cells are usually long and thread-like in places and contain a nucleus. The free end receives the stimulus, and the inner end is connected with a nerve cell which forms a pathway to the brain. Cells of this sort form the real sensory surface of the nose, tongue, ear, and eye and the sense organs of the invertebrates.

d. Germinal epithelium.—This is a specialized glandular epithelium in which the products of activity are fluids (*hormones*) to be later discussed, and sex cells, ova and spermatazoa.

e. Stratified Epithelium.—This forms the *epidermis* of the skin, the lining of the mouth and the anus. Just above the dermis is a layer of living and somewhat columnar cells. They are nourished from the blood vessels of the dermis. Cells in this *germinating layer* divide and one of the daughter cells is pushed toward the periphery. This occurs all along the line. Thus a series of layers of cells is formed. They become flattened and more scale-like toward the periphery and also lifeless. They are constantly worn and as constantly renewed.

2. Connective Tissue.—(Fig. 297.) Such a variety of tissue is found here that only a brief characterization is possible. The cells are subordinate to the substance outside or inside them. Connective tissue fills up spaces inside the body, connects different organs to one another, connects the tissues of any organ, forms rigid supports as in the case of cartilage and bone, or stores reserve food supply as in the

case of fat. In some of the sponges it forms a jelly-like mass with branching cells in it.

Fibrous connective tissue is characterized by a network of strong inelastic fibers. These may be interspersed with fewer yellow and elastic fibers. Ameboid-shaped cells are scattered in among the fibers. In Vertebrates the white fibers are arranged in bundles. When these run in all directions, as the connective tissues binding the skin to muscle, it is called *areolar connective tissue.* When the white

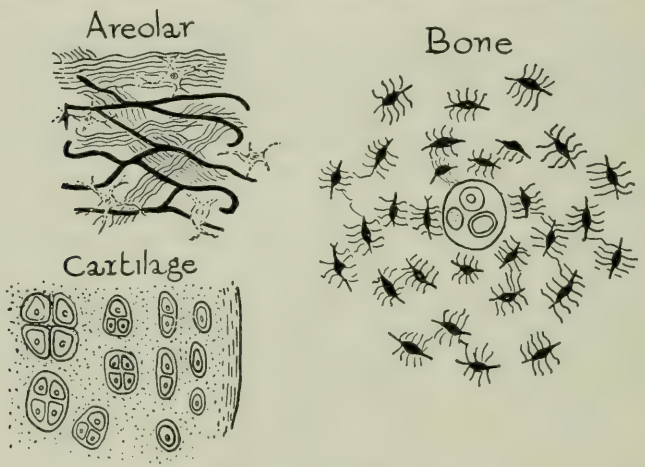

FIG. 297.—CONNECTIVE TISSUE.

Areolar containing wandering ameboid cells, parallel, non-branching, inelastic fibres and thicker, branching elastic branches. Cartilage with cells imbedded in matrix; Bone-Haversian System with canal in center with artery, vein and nerve; circular lamellae with lacunae from which fine canaliculi radiate out to other lamellae.

inelastic fibers are arranged in parallel bundles with cells between, the result is a tendon, a strong cord connecting muscles to bones. When boiled these yield gelatine. When no white fibrous tissue is present and a mass is formed of yellow elastic fibers, the result is a ligament which binds bones together. The ligament which connects the head to the backbone (*ligamentum nuchae*) of such animals as cows and horses is very important.

Cartilage and bone are also characteristic of Vertebrates. Cartilage consists of a homogeneous dense translucent matrix

in which scattered cells are found, singly or in small groups. Such clear cartilage is known as *hyaline* and connects the ribs to the breastbone. If it possesses elastic fibers imbedded in it, it is called yellow elastic cartilage.

Sometimes cartilage becomes hard by the deposition of lime salts as in old Elasmobranchs. This resembles bone in hardness but not in texture. Bone is formed in a cartilaginous ground substance. Special bone-forming cells (connective tissue) called *osteoblasts* have long radiating processes and they form bone in layers or *lamellae* around a cavity. The process is too complicated for further description here. In construction of bone the osteoblasts or bone cells become surrounded by bone. In canals in bone are *blood vessels*. Bone cells occupy little spaces called *lacunae* in the lamellae; the protoplasmic processes of the bone cells lie in tiny little channels (*canaliculi*) radiating in all directions from the lacuna. The canaliculi of lacunae of one lamella communicate with canaliculi of lacunae of neighboring lamellae. In this way bone cells in all the lamellae are fed from the blood supply and thus kept alive. In Man, bone contains 65 per cent inorganic to 35 per cent organic matter. The most important mineral salt is calcium phosphate. Surfaces of bone are covered with a tough vascular membrane called *periosteum* which attends to the nourishment of the bone just beneath it.

3. Muscle Tissue.—This is the special contractile tissue of the body. All protoplasm is more or less contractile, as illustrated by Amoeba which can contract and relax. But muscle cells are specialized for this function. In contraction they shorten in the direction of the long axis and become thicker across the short diameter. Limitation in the direction of contraction to one axis, makes for increased amount and rapidity of contraction.

The examination of contractile tissues of lower animals reveals some indication of the evolution of special contractile cells. In Hydra as in many Coelenterates for example, the inner ends of some of the ectoderm and endoderm cells are prolonged into contractile portions at right angles to the nucleated portion of the cell.

Two general types of muscle tissue elements occur in the Vertebrates (Fig. 298). The first of these is *smooth muscle.* The cells are elongated and spindle shaped, slightly larger in the middle and tapering at each end with an elongated nucleus in the middle. This is also called plain or unstriped muscle and is involuntary. It is sluggish in action and is employed to ensure contractility in ducts and tubes for which it is admirably adapted. Such muscle is abundant in Molluscs, forming the musculature of the sluggish moving foot. In Vertebrates it is found in the walls of the intestine,

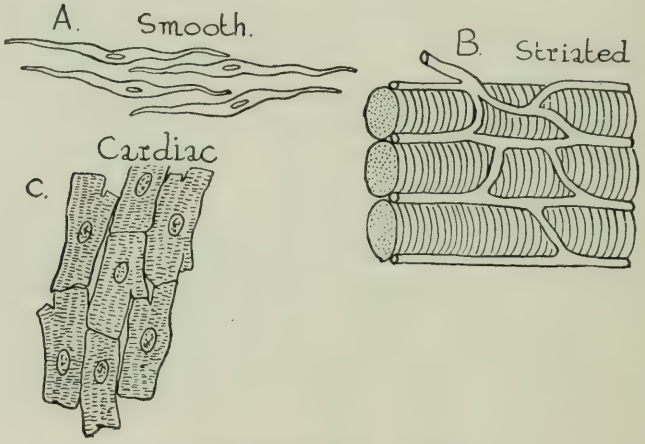

FIG. 298.—MUSCLE TISSUE.

A, Smooth muscle; long spindle-shaped cells; *B*, Parts of three striated muscle fibers with capillary supply; *C*, Seven cardiac muscle cells.

blood vessels, oviducts, bladder, and ureters. It also occurs in the lungs.

The second type is the *striated muscle.* The histological element is not a single cell but a multicellular, cylindrical, soft, rodlike structure about 150 mm. long and 10 mm. wide. This is the *striped muscle fiber.* It is covered with a soft sheath of protoplasm, the *sarcolemma.* Inside this are long, thread-like sarcofibrils imbedded in a liquid protoplasm. Several nuclei are located along its length just under the sarcolemma. A muscle such as the gastrocnemius of the frog or of man is made up as follows. The striped muscle

fibers (units) are arranged end to end in small bundles and bound together with fibrous connective tissue. Then several of these small bundles are in turn bound together by connective sheaths to form larger bundles and so on until the whole muscle is formed. The outside is covered with connective tissue. This is continued at each end into tendons which connect the muscle with the skeleton at its origin and insertion. The whole device is similar to an elastic cord consisting of rubber strands woven into a cloth fabric. The rubber corresponds to the muscle substance and the cloth to the connective tissue. One must distinguish between muscles as anatomical objects (i.e., biceps and triceps) and muscle tissue (fibers).

The above voluntary muscle elements are usually called *striped muscle fibers.* This is because each fibril is composed of alternating dark and light bands which show optical differences. The fibrils are so arranged that all the light bands are in line and all the dark bands are side by side. The result gives the appearance in the whole fiber of dark and light bands. These dark and light bands contain substances supposed to be actively concerned in the rapid and considerable shortening of this type of muscle which is remarkably adapted for swift locomotion.

The vertebrate heart is composed of oblong-shaped cells—the ends of which appear to be somewhat cleft or possess processes. These cells are uninucleated, contain long fibrils and there are indications of cross striation. Heart muscle does not move levers as does striated muscle. It is peristaltic as is smooth muscle, but it is more vigorous, more powerful, does greater work and moreover does it uninterruptedly and always up to grade. It is a very special type of muscle. The finger-like peripheral ends of motor nerves terminate among striped muscle fibers. A *motor nerve impulse* travels along the nerve, reaches the end plate and produces a change in the muscle, causing it to contract. In the case of smooth muscle and cardiac muscle on the other hand—the ordinary regular contractions are not dependent on the nerve impulses. These muscles are supplied, however, with nerves of two kinds whose

impulses speed up or slow down and increase or decrease the action.

4. Nerve Tissue.—This is composed of cells specialized for conveying impulses. Sensory nerves carry impulses from peripheral sense organs to the central nervous system, ganglia, spinal cord and brain. Motor nerves carry impulses from these to muscles, glands, etc.

In some Coelenterates some of the ectoderm cells are sensory and conductile at the periphery and contractile below, i.e., *neuro-muscular*. In Hydra there is further specialization, the periphery of some cells is sensitive, but the base is attenuated and acts like a nerve carrying an impulse to a deeper contractile cell. Or a superficial sensory cell may be connected basally with a deeper ganglion cell whose processes extends to a motor cell. In this is found, for the first time, a differentiation into the three kinds of organs of adjustment, i.e., of *irritability*, *conductility*, and *contractility*. In flatworms we find two long slender nerve cords ending in a thicker portion in front. A network of nerve fibers extends out from these cords. The nervous system of the earthworm, bee, and frog show further elaboration.

Nerve cells arise embryonically from ectoderm, which layer is exposed to external changes. Special sense organs are not always necessary as in some cases sensory nerves terminate in the skin and function as sense organs. The histological unit of nerve tissue is the *nerve cell* or *neurone*. Typically each neurone consists of a cell body containing a nucleus and cytoplasm. From the body extend branch-like fibers. These branches or dendrites conduct impulses into the cell. If the cell has many similar processes it is known as a multipolar cell. For conducting impulses over long nerves, as from the spinal cord to the toes, one of these processes grows out as a long fine thread and is called the *axone*. This is the characteristic form of motor nerve cells. (Fig. 153.)

In many sensory cells, on the other hand, there are two long processes, and they are called *bipolar cells*. A long process extends from the sense organ to a nerve cell body.

From this a shorter—possibly dendritic process—relays the impulse on into the spinal cord where its end may connect with a motor nerve cell. Multipolar cells, in which the axone immediately divides into a great number of branches inside the gray matter, occur in vertebrate brains as *association cells* to place in connection chains of sensory and

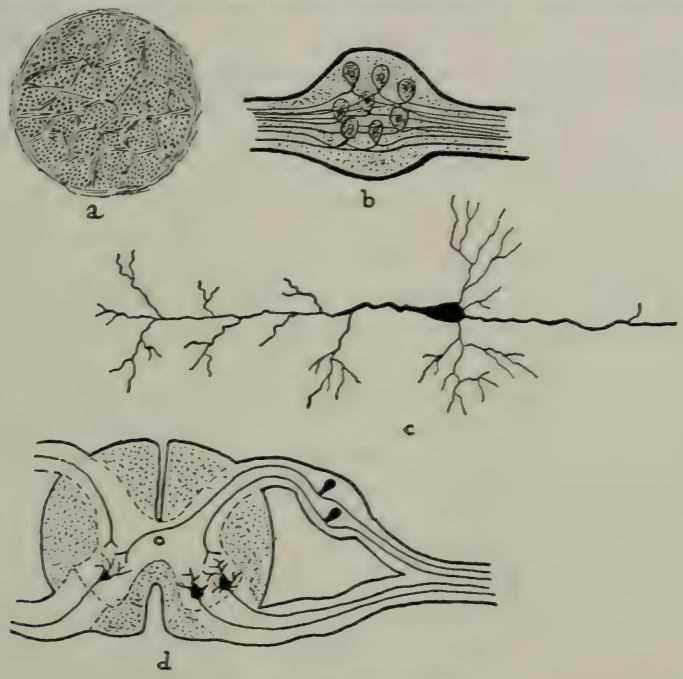

FIG. 299.—NERVE TISSUE.

a, Cross-section of nerve; bundles of axones surrounded by connective tissue; *b*, Section of ganglion with neuron bodies and axones; *c*, Pyramidal cell from cerebrum; *d*, Cross-section of spinal cord with gray matter inside and white matter around the gray horns. The posterior root has a ganglion in which is shown two cells; two motor cells in anterior horn have axones which run out in anterior root to spinal nerve.

motor nerves. The nerve cell body contains nucleus, granules, or a network of fibers. The external processes, such as the axone, consists of long fine neurofibrils imbedded in a liquid protoplasm surrounded by a protoplasmic sheath, the *neurilemma*.

A *nerve* (Fig. 299) consists of bundles (small bundles united

into large bundles,) of axones bound together by connective tissue. A *ganglion* is a group of nerve-cell bodies surrounded by such a covering. *Ganglia* are small nerve centers, and form the nerve centers of Annelids, Molluscs, and Arthropods. In Vertebrates the cell bodies are located inside the cord in the *gray matter*, a region somewhat resembling the letter "X." Surrounding the *gray matter* is the *white matter* forming columns of fibers. The fibers of the *dorsal columns* (posterior in man) carry sensory impulses from the periphery to the brain. The *ventral columns* (anterior in man) carry motor impulses from the brain to muscles. The lateral columns contain both types of fibers.

In the brain of Vertebrates we find in the *medulla* a number of internal ganglia of nerve cell bodies with their connecting branches. These internal ganglia or nerve centers are called *nuclei* in neurology. They are relay stations. They receive fibers from higher centers and transmit impulses down the cord, or vice versa. These Nuclei or "centers" occur elsewhere in the brain. The surface of the *cerebrum* and *cerebellum* is covered with a layer or rind called the *cortex*. This is gray matter. Here are located cell bodies whose axones stream down in converging masses to *internal brain nuclei and cells* to which lower axones are connected, etc. The interior of the brain is thus composed of fibers of white matter. Other cells form connections between one nucleus and another, between one part of the cortex and another (*association cells*) and between one hemisphere and another (*commissures*). Neurological histology is a complex science. Primarily, however, the most complicated nervous systems consist of neurones of two principal types—First, *sensory* for conducting impulses from peripheral sense organs to the internal central organ, and second, *motor* from the central organ to the muscle, gland. In Vertebrates a chain of one or more neurones may be involved in these two pathways. What shall be said of the histology of those cases where there is deliberation and thought occurring when the external stimuli are received and prior to the issuance of motor impulses? As far as is known, histology throws little light on this. In general

in bipedal, upright man, the back of the cord and brain contain sensory fibers while motor fibers occupy the front region. Indeed, enough is known to indicate to the trained neurologist a definite, orderly arrangement of parts in this most intricate of systems.

Two sorts of fibers are found. In white or medullated nerve fibers the axones are covered with a sheath of fat-like cells called *myelin*. It is supposed that this is an insulator. It occurs in peripheral cranial and spinal nerves of vertebrates. Sympathetic nerves are non-medullated. This type alone is found in the nerves of the hag fish, lamprey, Amphioxus, and in Invertebrates. Both types of axones are often surrounded by a sheath of *Schwann*, a delicate protective covering found in axones outside the central system. Histologically speaking there is no doubt that the frog has many more nerve cells than the earthworm, and man has many more than the frog. Also there is an increase in the complexity of the system in passing from earthworm to frog to man. It is worth while to contrast so far as possible the knowledge of the external world and degree of mastery over it possessed by the earthworm, frog and man. The organization of the nervous system shows a corresponding evolution.

It is only comparatively recently that the fact has been established that the nervous system is a system of *cells* called *neurones*. For a long time this was not accepted. During the period of controversy it was referred to as the "*Neurone Theory*."

5. Blood.—Blood is sometimes referred to as a tissue. It is rather a fluid, and should be studied from a physiological standpoint. Blood of animals consist of the fluid plasma and cells which float in it. White ameboid corpuscles have a wider distribution in animal bloods than the red blood corpuscles often associated with the white cells. It has been noted that white corpuscles are scavengers while red cells carry oxygen and, to a lesser extent, carbon dioxide. It would hardly be expected to find oxygen carrying cells, in forms so constructed as not to need them. And this is the case. Red blood cells are not found in Insects.

Invertebrate blood is usually colorless. It may be yellow-red or deep red as in some Molluscs, Annelids, and Insects. The color is due to *hemoglobin* which has iron in it.

In the cuttlefish, snails, lobsters, and spider-crab the blood has a greenish-blue tinge due to the presence in it of *hemocyanin*, a copper compound having an affinity for oxygen. Colored cells similar to red blood cells and containing hemoglobin are found in the coelomic fluid of some Annelids and in some Echinoderms. As stated above the colorless ameboid leucocytes are more often seen in Invertebrates, although even there they may be absent. Unless the body fluid in question contains food and wastes it can hardly be termed blood.

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CHAPTER XXIV

EMBRYOLOGY

Spontaneous Generation of Life.—In the seventeenth century William Harvey, the discoverer of the circulation of the blood, studied the development of the chicken. He believed that he had discovered a general biological law that " all life comes from the egg." References to asexual methods of reproduction in animals and plants indicate to us that Harvey's statement is not altogether true. It was many years later modified to " all living things come from living things." But this law was not established until about 1876. Prior to that time it was generally believed that many organisms originated from non-living matter by " spontaneous generation " as it was called. It was very natural, for example, for Aristotle in the third century B.C. to conclude that insects and frogs arose from mud. Bees, flies, mice, and rats were supposed to have originated in this way. Alexander Ross, in the eighteenth century, sarcastically wrote that " to question this is to question reason, sense and experience." In every age even authorities make dogmatic assertions which are without basis in experience.

In 1668, Frencesco Redi, an Italian, tested experimentally one of these common cases of spontaneous generation. He placed meat in several jars, some of which he left open, and covered others, some with wire gauze and some with parchment paper. The meat in all the jars decayed. Maggots (fly larvae) and flies appeared in the open jars. Neither fly maggots nor flies appeared in the parchment-covered jars. This showed that when flies could not get to the meat there was no spontaneous generation of flies. Thus it was found that there was no spontaneous generation at all. Flies lay eggs on decaying meat and the eggs develop into

flies. Flies come from flies. Other workers verified these results. Toward the end of the seventeenth century the compound microscope appeared and with the aid of it a new world of microorganisms was discovered, such as minute Algae and Protozoa. In 1687, the Dutchman, Leeuwenhoek discovered bacteria. It was now asserted that the origin of living things was from these organisms which arose spontaneously. This idea persisted until the latter part of the nineteenth century. The methods of reproduction and life history of these forms were gradually ascertained and it was learned that dust, air and, in fact, all things contain spores of such organisms and that these can *seed* any organic material left exposed to air, and also that the existence of hosts of such organisms is due to reproduction from parent organisms. Pasteur in 1860–64 (Fig. 300) by a series of most painstaking experiments, demonstrated the presence of microorganisms in air, and on dishes. He also showed that some of these organisms (*anaerobic*) did not need free oxygen, but could get it by their own ability to decompose organic substances.

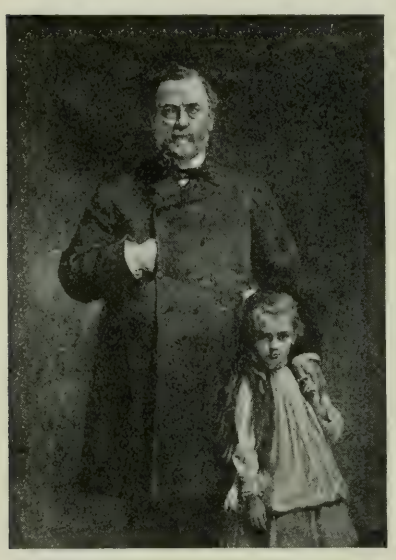

Fig. 300.—Louis Pasteur, great bacteriologist (1822–1895).

John Tyndall, the great English physicist, worked on optically pure air some time after this. He believed that such air, which contained no particles of any kind, would therefore, contain no microorganisms, and that if organic materials which had been heated to such a temperature as to destroy all living organisms in them were exposed to such air, that then no life would appear in them. Tyndall's experiments, published in 1876, were convincing. It was

proved that there was no spontaneous generation of life, and the age-long question was settled and to-day it is believed, as a general biological law, that so far as we know all living things come from living things. But this does not imply that life has always existed. If the astronomer's hypothesis is correct that this globe was once a molten ball, no form of life known to-day could have then existed. It has been suggested, however, that life units could have come to the newly cooled earth from some other planet. However, it is not known that life exists on other planets. The chemist knows that water is a union of hydrogen and oxygen. Water has not always existed. It was created when hydrogen and oxygen united to form it. Neither hydrogen nor oxygen have the properties of water. Water is a thing by itself. Moreover, it is now believed on good evidence that not even the present elements as we know them have always existed, that they have originated from preceding simpler things. So it is legitimate to suggest that living substance came into existence when the earth was cooling—when there was atmosphere and water and when certain compounds of carbon, oxygen, hydrogen, nitrogen and sulphur, etc., were brought together in a certain way. Just as oxygen and hydrogen existed (as in the sun to-day) before water, and as water is something new and not at all the same as oxygen and hydrogen, so living substance is not merely oxygen—hydrogen—carbon and nitrogen, even if these existed prior to the formation of living substance. Life is a peculiar phenomenon in itself. All notions as to the primal origin of life are speculations. That protoplasm arose spontaneously long ago is good speculation.

Development of Animals

Cell Division.—Development and growth involve *cell division*. This phenomenon, however, is not alone embryological. The cambium cells of ancient redwood trees are still undergoing cell divisions which have continued in some individuals for thirty centuries. Cells of some organs, such as pancreas,

liver, intestine, skin, etc., maintain a constant succession of cell divisions long after maturity, and most tissues divide as long as life lasts. It is necessary to understand this process as a preliminary to the study of Comparative Embryology. In a few cases the nucleus simply divides by fission into two nuclei. This is followed by division of the cytoplasm and there results two daughter cells. However, *direct cell division* is rare. Most cells divide by another complicated method, far more indirect. The former is called *amitosis* and the latter *mitosis*. Schleiden and Schwann, the founders of the cell theory (now the science of Cytology) in 1838–39, did not know of the process of cell division. The basis of this knowledge was gained between the years 1873 and 1879. In the latter year, Flemming suggested the name Mitosis for the process.

Mitosis.—In mitosis (Fig. 301) several changes take place simultaneously in the cell. Therefore, a description is difficult. Moreover, the process is continuous, but for convenience of presentation it is divided into four successive phases. 1. *Prophase;* 2. *Metaphase;* 3. *Anaphase;* 4. *Telophase.* The following description is generalized, i.e., it represents what is true of most cells. To understand it, a picture of a cell prior to mitosis, i.e., a resting cell must be studied. In this stage the cell wall is intact, and the spherical nucleus in the interior has a nuclear wall. A nucleolus may be present. Chromatin granules are in clusters (*chromomeres*) about the linin network, especially where linin fibers cross (net knots).

1. *Prophase.*—As mitosis begins the chromatin exhibits a greater affinity for certain dyes, showing that chemical changes are taking place. The chromatin granules assemble themselves to form a long thread, skein or spireme coiled somewhat intricately at first, but less so later on. The Greek word for thread is "*Mitos.*" In the meantime the nuclear wall and the nucleolus are disappearing. The centrosome outside the nucleus (rarely, if ever, present in plants) divides and each of these centrosomes moves away from the other. Around each centrosome appear radiating lines in the cytoplasm to form an aster (star). As the centro-

somes diverge more or less slightly, curved lines appear between them. The two centrosomes move away and down and around, each 90° from their starting place so that they come to rest at opposite sides of the cell, 180° apart. An axis passing through them is at right angles to a plane which would pass through the original centrosome and through the center of the nucleus. The lines from the asters now extend in all directions out toward the cell wall.

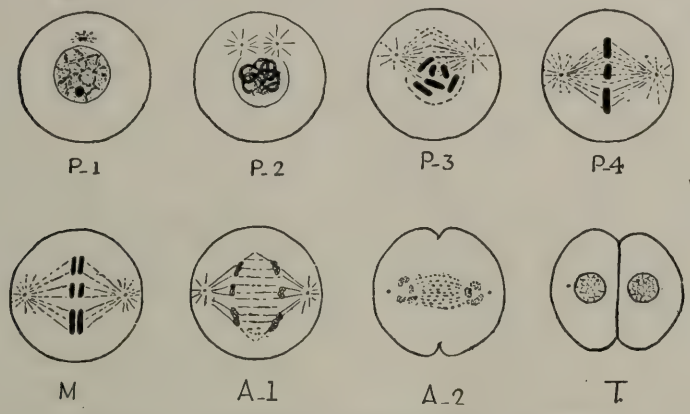

FIG. 301.—DIAGRAMS OF CELL DIVISION OR MITOSIS.

P-1; *P*-2; *P*-3; *P*-4; Stages in the prophase; *M*., Metaphase; *A*-1, *A*-2, Anaphase; *T*., Telophase. (After Wilson, The Cell, 3rd Edition.)

Spindle fibers extend across the cell between the two centrosomes. Spindle and asters are known as the *amphiaster*, or *achromatic figure*. What are these lines? Are they actual fibers or are they lines of force which have gathered protoplasmic granules along their course? The later behavior indicates that such physical properties as elasticity or tension are present. These spindle fibers penetrate in among the coils of the spireme. The *spireme* (chromatin thread) has divided into a number of pieces called *chromosomes*—the number being quite definite for each form of life. Thus in the onion and lily there are 16; i.e., in onions the cells have 16 chromosomes in mitosis. Ascaris has 4, the fruit fly has 8; and man has 48. Possession of a similar number of

chromosomes does not mean genetic relationship because some plants and animals have the same number. Later the chromosomes move into the equatorial plane which is at right angles to the axis, joining the two centrosomes. This plane is that described above as passing through the original centrosome. Some of the fibers appear to be attached to the chromosomes. All the sechanges belong to the prophase.

2. *Metaphase.*—Without stopping the chromosomes now split longitudinally, each forming a pair. Careful examination indicates that *each granule* is *exactly halved.*

3. *Anaphase.*—Continuing, the members of each pair now move away from each other and toward the nearest centrosome. The function of the anaphase is to provide each *daughter* cell with the same number of chromosomes possessed by the *mother* cell. Late in the anaphase a line and then a groove appears where the equatorial plane coincides with the wall of the cell. In plant cells small granules appear on the spindle fibers just where this plane passes through them.

4. *Telophase.*—This is the reconstruction of two new daughter nuclei and cells. The chromosomes on each side pass clear over to the respective centrosomes, the spindle and aster fibers and chromosomes begin to disintegrate. The groove in the cytoplasm deepens and two daughter masses of cytoplasm are formed, each with its own cell wall. A new nuclear wall is formed in each, and inside is nucleoplasm, linin network, chromomeres and a reformed nucleolus. By this time the centrosomes in each may divide in preparation for the next division and then they fade away to reappear when each daughter cell is about to divide again. This small daughter cell grows to the mature size of the mother cell. In the active cell division of embryonic life, cells sometimes divide so fast that they have no time to grow. That is, after repeated cell divisions of the fertilized egg, the embryo consists of hundreds of cells, each but a small part of the original size of the egg. There are many variations in the details of the process. For example, in higher plants there are no centrosomes; in some cells the

formation of a spireme is omitted. In plant cells there is no constriction by cleavage of the cell wall when in the telephase, because the cell wall is of cellulose. A cellulose wall is built up in the equatorial plane, but it should be remembered that this new cellulose is not hard and rigid, but soft and fibrous. What is the meaning of this complicated process? Apparently it is a most particular kind of division and the answer to the question seems to be that it is by mitosis that each daughter cell is ensured an equipment of chromatin, the exact counterpart of that of the mother cell. The bearing of this on heredity will be made plain presently. What are the causes of cell division? It has been found that reduction of the surface tension by chemical means causes certain eggs to divide, that the viscosity of the dividing cells increases up through the prophase and then decreases, also that the rate of oxidation increases and then decreases and that changes in electrical potential occur. But these are mere statements of observed physical and chemical changes which occur and which staining technique long before indicated. At present the causes of mitosis are not known.

Maturation.—Eggs and sperm are produced from ovary and testis cells by a series of mitoses, some of which are not the usual type. In each case there occurs a process of special preparation or maturation as it is usually called. Maturation of spermatozoa is known as *spermatogenesis*, that of egg cells is *oögenesis*.

A. Spermatogenesis. (Fig. 302.)—1. As a preliminary phase the cells of the testis that are to produce sperm undergo a series of ordinary mitoses. In this way a great many sperm mother cells are formed. This part of the process is called *the period of rapid multiplication.* The cells involved are called *spermatagonia.* At the end of the period, they are called *primary spermatocytes.* Each contains the same number of chromosomes as the spermatagonia cells, which is the number that would be found in all the cells of that species of animal. The maturation period follows.

2. *Period of Growth.*—When the period of rapid multi-

plication ends, the spermatocytes grow larger. At the same time the chromosomes fuse in pairs, side by side. If the spermatocyte cell had four chromosomes at the beginning of the growth period, there now appear only two. This process of fusion is called *synapsis*. In sexual reproduction an organism develops from a zygote cell, which is the result

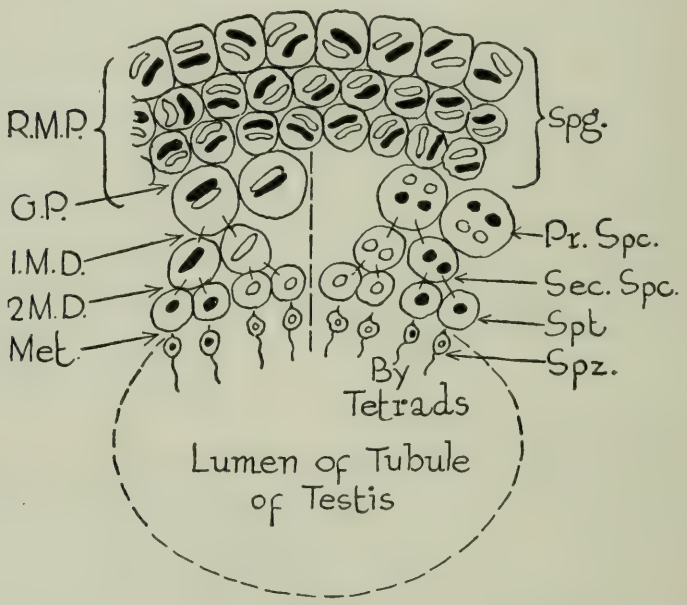

FIG. 302.—SPERMATOGENESIS. UPPER ROW OF CELLS, SPERMATAGONIA FROM OUTER WALL OF TUBULE OF TESTIS.

R. P. M., Period of rapid multiplication; *G. P.*, Growth period; 1. *M. D.*, 1st maturation division; 2 *M. D.*, 2nd maturation division; *Met.*, Metamorphosis; *Spg.*, Spermatagonia; *Pr. Spc.*, Primary Spermatocytes; *Sec. Spc.*, Secondary Spermatocytes; *Spt.*, Spermatids; *Spz.*, Spermatazoa.

of the union of an egg and sperm cell. The fertilized egg contains the same number of chromosomes as the cells of the parents, because the egg and sperm have only *half* the species number. By means of fertilization male chromosomes and female chromosomes come together, and during all the thousands of mitoses occurring in development and

during later life, these maternal and paternal chromosomes retain their original identity. This means, for example, that of the chromosomes in *all* body cells, half come from the mother and half from the father. During the growth period of maturation when the chromosomes fuse in pairs, a certain male chromosome fuses with a certain female chromosome, one by one, in definite order. Sometimes in synapsis the chromosomes do not appear double as just indicated, but in coming together they may divide and so each double chromosome may appear as a group of four. These groups are called *tetrads*. Two portions of each tetrad are maternal and two are paternal in origin.

3. *Division.—a.* As these duplex or tetrad chromosomes appear at the end of the growth period a *mitotic spindle* is formed and this divides the duplex chromosomes again, one portion of each goes into each of the two daughter cells. In the case of tetrads two dyads of the four bodies go into each of the two daughter cells. This mitosis is called the *first maturation* division, and the two daughter cells are called *secondary spermatocytes*.

In this division each secondary spermatocyte receives all the original maternal chromosomes, or paternal chromosomes or some of each. A great variation is possible. Apparently the purpose is to segregate in two different cells, chromosomes which had *all* been in the primary spermatocyte cell.

b. Now each secondary spermatocyte divides again—each forming two *spermatids*. Thus each primary spermatocyte forms four spermatids. In this second maturation division each spermatid receives half of any original maternal or paternal chromosome or in the case of tetrad formation, half of each dyad so that each spermatid receives one monad, i.e., one-quarter of each of the original tetrads. As a final result, each of the spermatids receives all the original paternal chromosomes, or some paternal and some maternal or all maternal, and so on. Again, great variation is possible. The process of maturation is a process of separating out the chromosomes present in the spermatagonia. It is necessary to understand this process because of its bearing

on heredity and evolution. The number of chromosomes of each spermatid is one-half the original species number.

4. *Metamorphosis.*—Each spermatid cell now undergoes a metamorphosis and develops into a functional spermatozoan with a head (nuclear part), middle piece (centrosome), and motile tail.

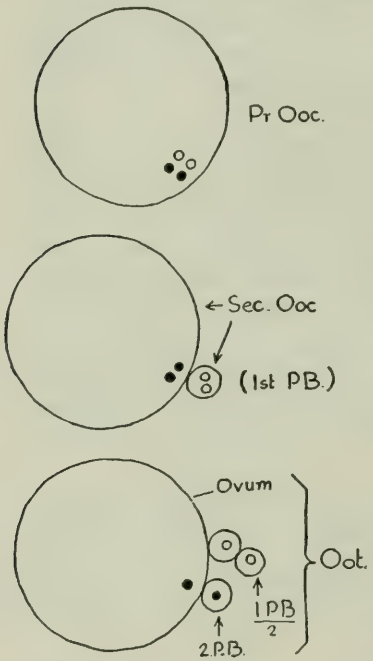

FIG. 303.—OOGENESIS. ONLY PART OF PROCESS IS INDICATED.

Pr. Ooc., Primary oöcyte; *Sec. Ooc.*, Secondary oöcytes, one is large, the other is 1st polar body; *Oot.*, Oötids—four; one is functional ovum, two are the divided 1st polar body, the fourth is the second polar body.

B. Oögenesis (Fig. 303).—Development of ova from the ovary is fundamentally similar to that of sperm. Oögonia in the ovary divide many times to form primary oöcytes. Then comes the maturation period. Internally the conditions are the same as in the sperm. That is, the chromosome behavior is the same. There is this difference, however. One of the two secondary oöcytes is very small and is called the first polar body. Although it has the same chromatic equipment as its large mate, yet it has scarcely any cytoplasm. The second maturation division occurs. The large secondary oöcyte forms a second polar body. The small secondary oöcyte (first polar body) divides into two polar bodies. All three polar bodies degenerate. Of the four oötids resulting from the two divisions, only one (large) is a functional egg. It was stated in the introduction that chromosomes are carriers of hereditary qualities. If spermatogenesis and oögenesis are reviewed it will be seen that sexual reproduction offers a means for securing variation, i.e., that offspring will not be replicas of their parents. For

neither spermatozoan nor egg contains all the chromosome equipment of their respective originators. When the chromosomes of a sperm are added to those of an egg, the species number is restored, but there is a new combination of chromatin. The ovum contains only part of the chromosome equipment and qualities of the female which produced it. The qualities represented in the polar bodies are lost so far as the individual is concerned, which develops from that egg after it is fertilized.

Fertilization.—The sperm may enter the egg before oögenesis is complete or afterward. There is variation in this. Some eggs are covered with a thick membrane through which sperm cannot pass. This membrane contains small passageways here and there called *micropyles*. Through one of these a sperm may enter. If this happens all other micropyles become closed. If the egg has a thin membrane a sperm may enter through it, then a fertilization membrane is formed which usually prevents entrance of any other sperm. However, if more than one enters, normal development does not follow unless but one of the sperm actually takes part in development. There is no doubt but that sperm are attracted toward eggs. The latter have some sort of chemical affinity for them. Spermatozoa introduces some chemical change which starts up the processes of development. It is analogous to a wound-up clock which is not going. The sperm starts the pendulum swinging, so to speak. In addition to its stimulating effect, the chromatin of the sperm nucleus (head) contributes as much to the heredity of the organism as does the egg. Only the head and middle piece enter the egg. The sperm nucleus is much smaller than the egg nucleus. The latter may be at some point near the periphery of the egg cell where the polar bodies are given off. When this is completed the egg nucleus moves toward the sperm nucleus and the latter toward the egg nucleus until they meet near the center of the egg, if the egg is without yolk, as that of Asterias or Ascaris, a mitotic spindle appears and in the equatorial plane appear the paternal chromosomes introduced with the sperm and the maternal chromosome of the

egg. Now the cell divides into two and thus cleavage begins.

Cleavage.—(Fig. 304.) The egg divides into 2, 4, 8, 16, 32, etc., cells, which becomes smaller and smaller as there is no increase in mass of the dividing egg. Each cleavage plane is at first at right angles to the preceding plane, although there is some shifting. Eggs possess polarity. In some eggs, as that of the frog, one end is denser in protoplasm while the opposite end is denser in nutritive

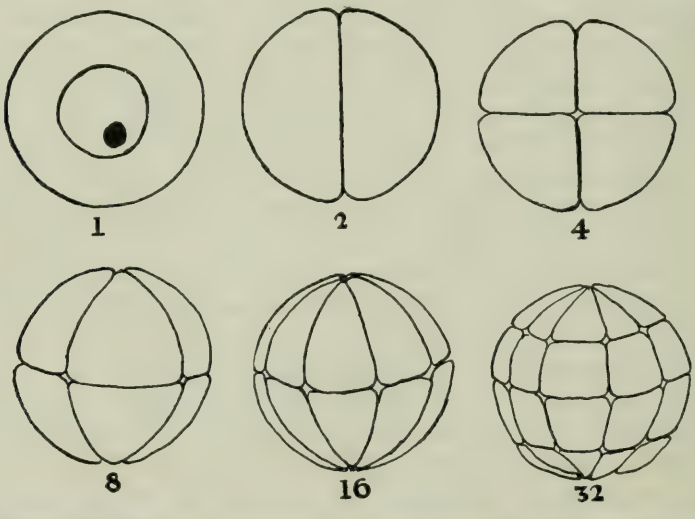

FIG. 304.—STAGES IN CLEAVAGE IN A SIMPLE EGG AFTER FERTILIZATION. 1, 2, 4, 8, 16, 32 CELL STAGES.

materials (yolk). The end more dense in protoplasm is called the animal pole; the other, richer in food material, is the vegetal pole. Even the egg of amphioxus, with very little more nutritive material at one end, exhibits polarity, the nucleus being nearer one end than the other. Most Coelenterates, most Echinoderms, some Molluscs, Annelids, Amphioxus, and higher Mammals have eggs of this sort. The frog's egg contains a great deal of yolk. There is no sharp line of demarcation

between the animal and vegetal regions. They grade into one another. In Fish, Reptiles, and Birds the embryonic egg protoplasm (containing the nucleus) occurs at the animal pole and is sharply marked off from the great mass of the egg which contains yolk toward the vegetal end. In insect eggs there is a central mass of yolk. In the center is the nucleus surrounded by a small mass of cytoplasm.

The presence and distribution of yolk modifies cleavage planes. *Homolecithal eggs* are those of the first type; *telolecithal eggs* are those of the second and third type present in Amphibia, Reptiles, and Birds; while centrolecithal eggs

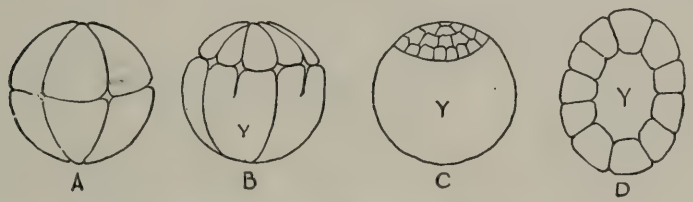

Fig. 305.—Types of Cleavage.

A, Equal holoblastic; *B*, Unequal holoblastic; *C*, Discoidal meroblastic; *D*, Superficial meroblastic; *Y*, Yolk.

are those of the third type, present in Arthropods. The homolecithal egg exhibits the simplest mode of cleavage and development. This simple plan is departed from in the other animals due to the presence of yolk.

Four chief types of division are recognized: First, complete or holoblastic. In this the entire egg is divided into cells. But there are two types of holoblastic cleavage.

A. 1. In *homolecithal* eggs with little and diffuse yolk, the resulting cells are about *equal* (Fig. 305). The first cleavage plane passes through the animal and vegetal poles meridionally and bisects the egg. The second plane of cleavage is at right angles to the first, and is also meridional, forming four equal cells. The third plane is equatorial, cutting off four cells at the animal end and four at the vegetal. The fourth and fifth planes are meridional and

in between the first and second and at right angles to each other. This makes eight cells above and eight below the third plane. The sixth plane is parallel to the third and between it and the animal pole, making sixteen cells above. Almost at the same time, the seventh plane comes in between the vegetal pole and the equatorial plane and parallel to it. This makes sixteen cells below or thirty-two in all. Cleavage planes rapidly succeed each other now and the geometric regularity is gradually lost. All the cells are of about the same size.

2. *Unequal holoblastic.*—Such an egg divides completely, but the resulting cells are unequal in size. At the time the first equatorial plane forms there are four small cells above and four larger cells below. Then eight cells are formed at the animal pole above before the larger four vegetal poles have divided. The greater amount of yolk here seems to delay segmentation. This type of division is found in some Sponges, some Coelenterates, some Worms, Molluscs, in Petromyzon, some Fishes and in Amphibia (frog's egg).

B. *Incomplete or meroblastic segmentation.*—(1) Only the protoplasm at the animal pole divides. The yolk remains undivided. This is called discoidal segmentation for the 16, 32, 64 cells form a little disk over the yolk at the animal pole. This occurs in some Molluscs (squid), Elasmobranchs, Teleosts, Reptiles, Birds and Monotremes. (2) Superficial. When cleavage occurs, the cells migrate to the peripherv of the yolk. This is characteristic of the Arthropods.

It is evident that no particular type of cleavage is connected with the difference in degree of specialization of the type of animal. It is more related to the conditions under which development occurs. A mature adult results despite the differences in mode of cleavage. Very early in development and long before maturity the starfish and amphioxus embryos become free-swimming and food-gathering. In those cases where much yolk is present, the simple type of cleavage becomes complex. In higher Mammals where placental feeding is resorted to, practically no

yolk is needed. The early cleavage stages are very simple, but soon depart from this on account of the highly specialized structures that have to be developed in connection with embryonic nutrition.

In this brief characterization of the development of animals only the simplest picture will be presented. Illustrations of steps in development that can be most easily comprehended will be taken from any of the four above classes as needed. It is not possible here to explain how special modifications due to incidental conditions can be shown to fall into line with one general plan which is clear to the student of embryology.

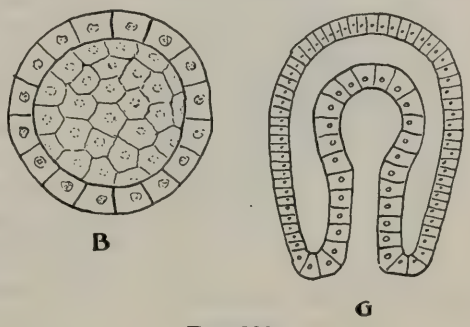

FIG. 306.

B, Blastula and *G*, Gastrula of starfish, diagrammatic.

Morula and Blastula.—Cleavage soon produces a ball of cells in homolecithal eggs. This is a *morula* and is best seen in this type of egg. As segmentation advances a cavity appears inside. This stage is called the *blastula* (Fig. 306). It is like a hollow ball whose wall is composed of one layer of cells. The cavity within is the *segmentation cavity*.

Gastrula.—The cells at one place in the blastula now grow in by a process of *invagination*. It continues until the inturned cells are in more or less contact with those outside. Thus a two-layer double sac-like stage is produced. The inner layer of cells forms the endoderm. They may be a little larger than those of the outer ectoderm layer. The space, if any, between ectoderm and endoderm is still the segmentation cavity. The mouth is called the *blastopore*. The cavity of the endoderm is the *archenteron* or primitive gut. Thus two primary germ layers are formed. The ectoderm may be regarded as related to functions of *adjustment*, the endoderm to functions of *metabolism*. A review of the

anatomy of Coelenterates shows that they are but specialized gastrulae.

Mesoderm.—The origin of this third primary germ layer is diverse (Fig. 307). In one type of animal it arises in one way, in another type, differently. There is no mesoderm in Porifera or Coelenterates. It is clearly represented in Platyhelminths and higher phyla. Mesoderm may arise from primary mesoblast cells (*mesoderm formers*) appearing in the segmentation cavity as in the earthworm, or from wandering mesenchyme cells that come from gastrula cells from ectoderm or endoderm, or by pouches on either side of the endoderm tissue of the gut of the gastrula. These increase in size until they fill the segmentation cavity and become cut off from the gut of the gastrula. The pouch cavities form the *coelom*. The outer somatic mesoderm associated with the body wall develops in part into skeleton and muscles; the inner sheet is associated with the intestine and in part develops into intestinal musculature and connective tissue. In higher Vertebrates its origin is less clear.

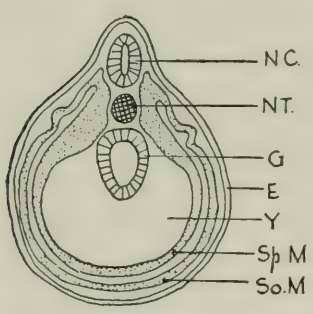

FIG. 307.—CROSS-SECTION YOUNG AMPHIBIAN EMBRYO.

N. C., Nerve cord; *N. T.*, Notochord; *G.*, Gut; *E.*, Ectoderm; *Sp. M.*, Gut mesoblast (splanchnopleure); *So. M.*, Body wall mesoderm (somatopleure). Compare with amphioxus section. (From section and after Marshall.)

Before proceeding to a brief description of the development of organs, the fate of each embryonic germ layer is given.

(1) *Ectoderm.*—Epidermis and its products (hairs, etc.,) nervous system, sensory portions of sense organs, and lining of the front and rear end of alimentary canal.

(2) *Mesoderm.*—Dermis, connective tissues (fat, cartillage, skeleton); muscles, skeletal and that of blood vessels, heart, uterus, intestine, etc.; peritoneum, kidneys, reproductive organs and structures related to them.

(3) *Endoderm.*—The lining of the greater part of the

alimentary tract, lining of trachea and lungs, gland cells of intestinal tract, of pancreas, liver; notochord (Fig. 308).

Organogeny.—This refers to the development of organs from the three germ layers. Certain growth processes occur over and over again. Folds are formed, grooves appear which become tubes, sacs are formed, tubes grow out and tubes grow in, etc. Invagination means the growing in of cells to form a tube or sac, possibly, inside the cavity of another tube or sac. Evagination is the opposite of this.

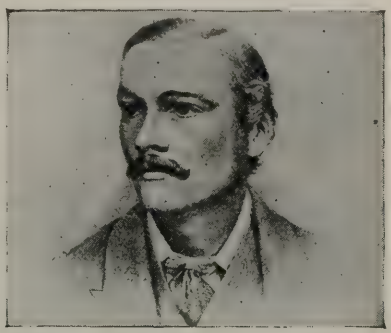

FIG. 308.—FRANCIS BALFOUR (1851–1882), AUTHOR OF "COMPARATIVE EMBRYOLOGY."

But a few indications as to how organs are formed will be given and these illustrations are from the Vertebrates and the frog in particular. They are true in general of all Vertebrates. (Fig. 309.)

The frog gastrula elongates somewhat and anterior-posterior, dorso-ventral differentiation and bilateral symmetry is established. A groove (neural groove) appears in the ectoderm along the dorsal mid-line. On either side of it longitudinal folds (neural folds) grow up, leaving a trough between. The edges of these folds meet and grow together with the result that a long hollow tube of ectoderm is formed under the ectoderm of the surface and under the dorsal mid-line. This tube is blind in front, at which end the brain develops, the greater part of its length becoming the spinal cord. From cells in its walls nerves grow out. The front end of the neural tube increases in size when the brain forms. In front it grows down around the end of the notochord. Soon two folds develop internally dividing the brain portion into (*a*) fore, (*b*) mid, and (*c*) hind brain. From the fore-brain develops the (1) *prosencephalon* (cerebrum) and (2) the *diencephalon* (between brain). From the mid-brain develops the (3) *optic lobes* or *mesencephalon;*

and from the hind-brain (4) the *metencephalon* or *cerebellum* and (5) *myelencephalon* or *medulla.*

The *notochord* arises as a proliferation of cells along the dorsal mid-line of the archenteron of (*embryonic gut*). It is later surrounded and invaded by a certain kind of mesoderm cell of a sort which constructs a cartilaginous skeleton. Later bone (mesoderm) also appears to replace the cartilage. The blastopore of the gastrula does not continue as the anus of the adult animal. A pit appears near the blastopore and this deepens (invagination of ectoderm) until it connects with the embryonic gut. The old blastopore closes up. The new opening is the anus. The front end of the embryonic gut is blind. A pit appears in the ectoderm opposite it. This pit deepens to a short tube. (Invagination of ectoderm). The blind end of the embryonic gut grows forward to meet this tube. The two meet and their end walls disappear so that a mouth is formed and now there is a continuous passageway from mouth to anus, that is, a tube within a tube.

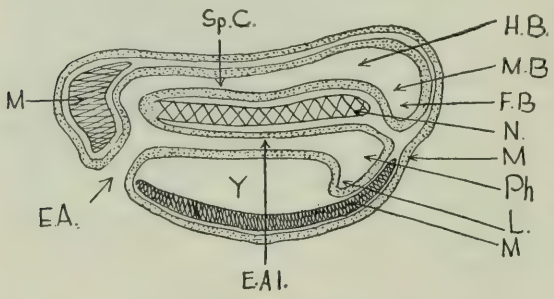

FIG. 309.—DIAGRAM OF LONGITUDINAL SECTION OF FROG EMBRYO.

M., Mesoderm; *Sp. C.*, Spinal cord; *H. B.*, Hind brain; *M. B.*, Mid brain; *F. B.*, Fore brain; *N.*, Notochord; *Ph.*, Pharynx; *L.*, Liver; *Y.*, Yolk; *E. Al.*, Embryonic gut; *E. A.*, Embryonic anus; *M.*, Opposite Pharynx is point where mouth forms. (From section and after Marshall.)

Gill slits begin as lateral, pouch-like outgrowths from the endoderm of the enlarged front end (pharynx) of the gut. These pouches grow out and fuse with the ectoderm, then slits break through.

Thyroid gland, lungs, liver, pancreas, and cloacal bladder start as tubular or saccular outgrowths (*evagination*) of cells (endoderm) of the embryonic intestine. The thyroid

later loses its connection with the gut and becomes a ductless gland. The lungs start as a pit growing out of the gut on the floor just in front of the stomach (evagination of endoderm). The tube is single at first, then grows into a right and left branch. The stalk is the *trachea*. The main branches are the *bronchi*. The terminal portions increase to sacs with alveoli on the inner walls. The lining of the respiratory system is endoderm. But mesoderm is largely concerned, for it wanders in, forming a connective tissue framework and is present also in blood vessels and plain muscle. Ectoderm is represented in the nerves of the lung.

The *liver* begins like the lungs, as a tube but on the ventral floor of the intestine just behind the stomach (evagination of endoderm). It soon becomes branched and branching tubular outgrowths continue to be formed until a complicated branching tree-like mass of tubes is formed. The terminal portions of the tubes are glandular liver cells, the more tubular parts are collecting ducts for bile, the first evaginating tube is the bile duct. Mesoderm again fills in the spaces between the glands and ducts with connective tissue and blood vessels, etc. Nerves are present.

The *pancreas* originates and develops like the liver as two evaginating pouches from the gut. The cloacal bladder forms as a sac-like diverticulum from the floor of the hind gut. Its wall is strengthened with mesoderm (connective tissue) and it remains as a very thin-walled, somewhat elastic sac.

Allantois and Amnion. Fig. 310.—In Reptiles and Birds, the embryo develops in a disk of cells on the yolk inside the white of the egg and its shell. An early indication of the embryo is a thickening in the middle of this disk. The development of organs occurs as before. But the periphery of the disk grows down around the yolk. The superficial layer of the disk is ectoderm lined with mesoderm, while next to the yolk are endoderm cells, with mesoderm above, i.e., splanchnopleure. Before this is completed a fold of *somatopleure* (ectoderm and mesoderm) grows up in front of the head. Similar

folds appear on each side of the embryo and behind. These folds grow up around the embryo and meet above it. They are double and, after they meet, the inner layer fuses with the inner layer and the outer layer fuses with the outer layer. This encloses the embryo in a sac called the *true amnion* and above this is the *false amnion*. The true amnion (sac cavity) is filled with a fluid bathing the embryo. Externally the true and false amnion are in contact unless prevented by presence of some other structure. The am-

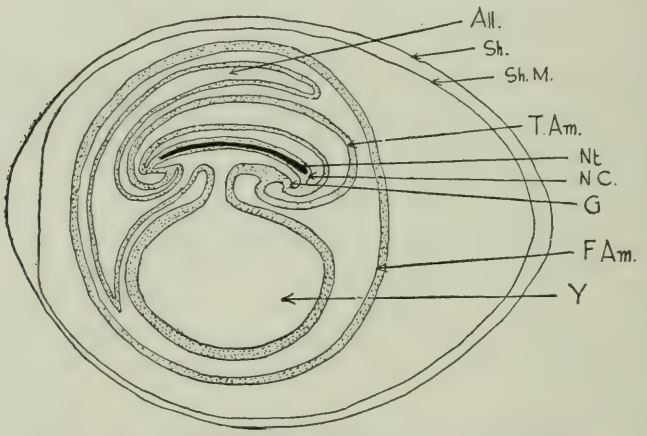

FIG. 310.—CHICK EMBRYO IN SHELL—DIAGRAMMATIC.

Sh., Shell; *Sh. M.*, Shell membrane; *All.*, Allantois; *T. M.*, True amnion; *Nt.*, Notochord; *N. C.*, Central canal of brain and spinal cord; *G.*, Gut; *Y.*, Yolk; *F. Am.*, False Amnion. (Modified from Gegenbaur in Prentiss.)

niotic fluid protects the embryo from physical shocks when the egg is moved. The splanchnopleure grows around until it completely encloses the yolk, thus forming a yolk sac. This is connected with the embryonic gut.

As the amnion is growing, a sac called the *allantois* grows out from the floor of the hind gut. This is lined with endoderm (as is the gut) but outside it is covered with mesoderm (splanchnic) as is the gut. It grows out and above and below the embryo between the true and false amnion. Its walls possess veins and arteries which are in connection with the blood system of the embryo. It is a respiratory

organ for the embryo. Oxygen enters through pores in the egg shell, and through the white of the egg into the capillaries of the allantois and so to the embryo. In reverse fashion the CO_2 passes out. Wastes of later embryonic development collect in it. The yolk in the yolk-sac is grad-

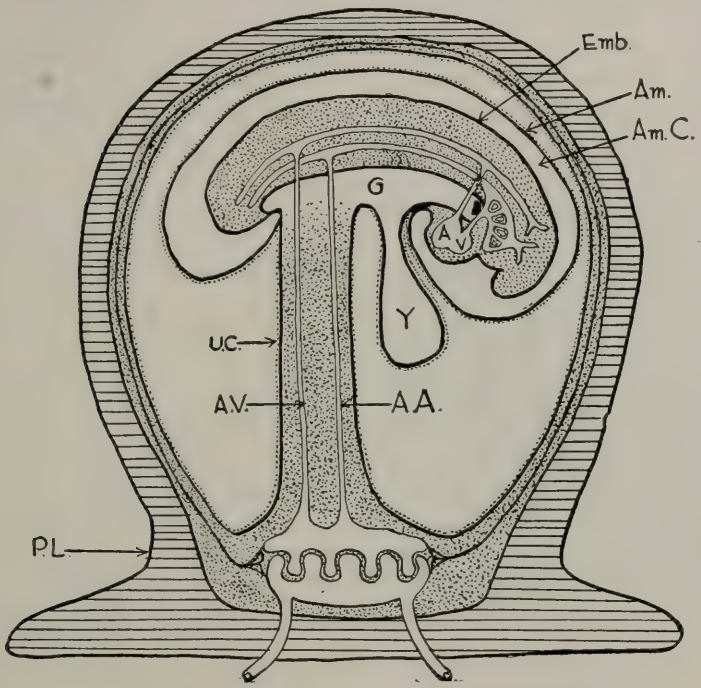

FIG. 311.—DIAGRAM OF EMBRYO AND PLACENTA.

Emb., Embryo; *Am.*, Amnion; *Am. C.*, Amniotic cavity; *G.*, Gut of Embryo; *A.*, Auricle of embryo which receives blood from body of embryo and from *A. V.* Allantoic vein from the placenta; *V.*, Ventricle of embryo heart which drives blood out to body of embryo and into *A. A.*, Allantoic artery and so into placenta; *Y*, Yolk; *U. C.*, Umbilical cord; *Pl.*, Placenta. (Modified from Prentiss.)

ually absorbed. When the animal is ready to hatch, it bursts through the amnion, false amnion and shell, and is parted from all the above structures. Their usefulness is over. The allantois is homologous with the cloacal bladder of Amphibia.

Placenta (Fig. 311).—The placenta, as has been described, is a structure which vitally connects mammalian mother and offspring. It is formed by a union between a portion of the uterine wall and part of the false amnion and allantois. The allantois structures of *Sauropsida* are retained and used in a new way, due to the absence of yolk and due to a superior method of rearing, which is wholly intrauterine. But there are hints of a placenta-like structure in lower animals. This false placenta is found in some Elasmobranchs, Teleosts, Lizards, Turtles, and Birds. It is a junction between the wall of the uterus and the yolk sac.

In the mammal embryo, amnion and allantois are formed. The true amnion forms a sac filled with liquid in which the embryo lies protected. The false amnion is in contact with the wall of the uterus. The outer face of vascular allantois is in close connection with the inner face of part of the false amnion that is, in contact with the wall of the uterus. Both uterine wall and false amnion and allantois grow in thickness where they are in contact. Finger-like processes from the embryonic structures grow out into the uterine structure. The peripheral ends of uterine and foetal blood vessels increase to large sinuses whose walls are in close contact. The maternal blood is in close contact with foetal blood. A temporary yolk-sac placenta occurs for a time in some forms. This degenerates and the final and important placenta is that with which the allantois is concerned. The umbilical cord is the long and modified neck of the allantois. The cord contains arteries and veins connecting the foetus with the placenta. There are different types of placentae. *a.* In some Ungulata it is *diffuse*, that is, connections with the uterine wall are made over a wide area. *b.* It is *zonary* in Carnivora in which the placenta is like a *girdle* inside the uterus. *c.* In the Primates (man) it is *discoidal*, or saucer shaped and is in intimate connection with uterine tissues. At the center of the opposite face is the *umbilical* cord.

General Considerations.—In review it is important to note that:

a. Most sexually reproduced animals begin life as a *single cell*, the ovum. This might be called the Protozoan stage of development.

b. Early cleavage stages form a *morula*, a spherical group of cells. Associations like this are found in Protozoa, for example, Pandorina.

c. Later cleavage produces a *blastula*, a hollow ball of cells. Volvox is like this.

d. Later the embryo forms a *gastrula*. But Hydra and Coelenterates have this body plan.

e. Reptile, Bird and Mammal embryos have gill slits and gill arches and never use them. They are adult structures in fishes and some Amphibia.

f. Pro- and *mesonephros* are embryonic structures in Reptiles, Birds and Mammals. The *pronephros* is functional in adult Cyclostomes and embryos of Ichthyopsida.

Fig. 312.—Von Baer—pioneer embryologist (1792–1876).

It is possible that the higher animal in its development goes through its whole ancestral history rapidly recapitulating this, as it were. Von Baer, in 1828–34 (Fig. 312), making a general and comparative study of the embryology of animals, concluded that early in development widely separated animals, such as Reptiles, Birds and Mammals, had so many characters in common that he could with difficulty distinguish between them and that development proceeded from a general to a special type.

But Fritz Müller, in 1863, went further than this. He expressed the opinion that the embryological history of an animal indicated ancestral stages through which

it passed. Haeckel, in 1874, accepted this theory completely. It is known as the Recapitulation Theory or *Law of Phylogenesis*, which is that ontogeny recapitulates phylogeny—that an animal in its development goes through stages indicating or representing its ancestors. Since starfish, earthworm, snail, amphioxus, frog, and man have a gastrula stage—this indicates that their ancestor was a Coelenterate-like animal. The fact that they all start from a single cell means that the original ancestor was a Protozoan; and since Sauropsida and Mammals had gill slits, that is an index of their fish-like ancestors. Though there is *some* truth in this theory, yet embryological history does not show *all* details of ancestral history. Special conditions of development necessitate special structures. Development of the individual is accomplished in an extremely short time as compared to phylogenetic history, so it is to be expected that but few ancestral details would appear. It is difficult to distinguish between ancestral characters and those peculiar to the particular method of development involved. The application of the so-called law of phylogenesis is indeed limited.

It seems axiomatic, to any one who studies the embryology of an animal from a fertilized egg, that a large and complex organism develops from an apparently simple microscopic mass of undifferentiated protoplasm. Charles Bonnet (1720–23) who first discovered parthenogenesis in Aphids, philosophized deeply concerning development. He satisfied himself that, after all, there was no development but that the egg contained in its small compass all the elements of the adult. Nothing new appeared, only the gradual unfolding of what pre-existed. Thus arose the embryological doctrine of *Preformation*. This had really been introduced in the preceding century by Swammerdam, Malpighi and Haller. But Bonnet carried the idea to absurd limits. If the animal is preformed, an animal of the next generation is present in it in still smaller compass and so on ad infinitum. All thinking along embryological lines was dominated by this idea during the seventeenth and eighteenth centuries. It was even computed that Eve,

the mother of all men, possessed 200,000 millions of homunculi (little men) in her body. Indeed, the preformation school divided into the *Ovists* and *Animalculists*. According to the former, it was the egg that contained miniatures of future descendants. But spermatozoa had been discovered and so others (Animalculists) believed that the sperm alone functioned in this, and that the eggs are only soil in which the organism resident in the sperm, could develop.

Speculation followed speculation. In 1759, Wolff checked all this by masterful studies based on painstaking observations on the development of the chicken and published in a paper called "*Theoria Generationis.*" He showed that the early embryo contained no future parts but that the organs appeared gradually one after the other. From early simple substance, differentiation to later complexity took place. In other words, there was no mere unfolding of parts already formed. This is known as the *Doctrine of Epigenesis.* It served to call forth for many years a period of careful investigation of the development of organisms. But experiments carried on during the latter part of the nineteenth century demonstrated that preformation of a sort *is* true of eggs. For example, in the egg of Cynthia, a Tunicate, the cytoplasm of the egg shows five different zones or bands of protoplasm, 1st, clear; 2d, light gray; 3d, dark gray; 4th, light yellow; 5th, dark yellow. As development proceeds these are parceled out to definite groups of cells and organs. The clear protoplasm becomes *ectoderm;* the dark gray becomes *endoderm;* the yellow becomes *mesoderm.* If the egg is punctured and the clear substance removed — the embryo possesses no ectoderm and can produce no ectodermal structures. Of course, such an embryo does not mature. This demonstrates a certain kind of preformation. Other eggs are not differentiated so early as the one-cell stage. This is known to be true of the eggs of the sea-urchin and amphioxus. If such an egg is punctured and some of the cytoplasm is removed a perfect embryo results. If in the two-cell stage, one is destroyed or the two separated, perfect embryos result. Any cell of the 4-, 8- or even 16-cell stage has the

power of forming a perfect but smaller embryo. Sooner or later, but comparatively early, however, differentiation appears and this is no longer possible. Eggs differ in this promorphology. The sea urchin egg is more generalized than that of Cynthia.

Indeed these experiments show the truth of both preformation and epigenesis, for they demonstrate the gradual development of the complex from the simple as well as showing the presence of a certain degree of promorphology. The experiments also throw light on the origin of identical human twins. It is probable that the fertilized egg goes into the two-cell stage normally. Then these get separated in some way. Each cell develops into a perfect mature organism and the two are remarkably similar. When one stops to consider the similarities in stature, figure, features, hair color, eye color and even mental characteristics of two identical human twins derived from a mere speck of protoplasm about 0.25 mm. in diameter, one is forced to definite conclusions as to the generalized conditions of the germinal cell and the equal distribution in it of its elements. Although there are definite indications of promorphology of egg cytoplasm, yet a still more significant organization is present in the chromosomes and is discussed in the study of Genetics.

The course of development does not always run smoothly. Possibly unusual chemical or physical conditions change it. Abnormalities often appear. Organs are misplaced or incomplete, or lacking, or out of proportion, or doubled. One or both legs may be lacking or one or both arms or all four lacking. Experiments on eggs and embryos of lower forms throw light on these matters. If the developing limb bud of a frog is destroyed no limb will develop, if all the " limb-forming substance " is destroyed. Suppose the two-cell stage be partly separated. Then a two-headed and one-bodied embryo may develop, or one-headed and two-bodied or two-headed, one-bodied and two tailed. All sorts of combinations have been produced.

Similar cases are found even in human beings. A pair of twins was born with almost two complete bodies. The

twins were joined so that the posterior end of the backbone was common to both. It is remarkable to note that one suffered from a contagious disease and the other did not. This illustrates differences in the presence of much that was similar; but when one died, the other became mortally ill a very short time afterwards. Many people believe that abnormalities are sometimes due to prenatal influences; that shocking incidents so impress the mother as to affect the normal development of her child and mark it in some way. A common story is this: A pregnant mother was frightened and shocked at the sight of a mad dog biting a child on the arm. As a result her baby, when born, showed a red scar in a corresponding place. There is no scientific connection between the phenomena. Many babies have been born with scars on their arms, although their mothers never saw a mad dog. Mothers surrounded by the most favorable conditions during pregnancy have been known to give birth to abnormal offspring. The possibility of any specific effect of prenatal influences of the above sort is highly improbable.

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CHAPTER XXV

PHYSIOLOGY OF ANIMALS

Introduction.—It has been pointed out that what is called life consists of a characteristically complex series of changes exhibited by a certain kind of organization of chemical elements and compounds, called protoplasm. The preceding pages contain brief descriptions of different types of organizations considered chiefly from the morphological point of view. A general account of the physiology of the Cell and Protoplasm was given in the introductory chapter. As each group was taken up general statements with regard to physiological processes were made. For convenience these vital processes were divided into three groups: 1st. Those of *metabolism* which, from this point of view, refers to those processes concerned in keeping the organism simply a "going concern" analogous to a stationary motor car whose engine is "idling," i.e., running, although the machine is not progressing; 2d. Processes of *adjustment* referring to those processes concerned in the adjustment of the organism to the environment; 3d. Processes of *reproduction.*

The word metabolism as used in the above classification refers to such matters as ingestion of food, digestion, secretion, circulation, respiration and excretion. In the physiological use of the word *adjustment,* is included the functioning of such systems as the organs of *sense* (receptors) *conduction* (adjustors) or nervous systems, and *motion* (effectors), muscular systems. The word *reproduction* needs no further comment.

In single-celled Protozoa all these processes are carried out by one cell. Moreover, it is altogether likely that more than one process is going on simultaneously in any single Protozoan.

The evolution of the Metazoa from the simpler types to the highest involved the gradual building up of special groups of cells, tissues, organs or organ systems for the more efficient carrying out of special functions. Yet all the functions are necessarily displayed by both Protozoa and Metazoa.

Physiology of Specialized Cells.—The chief function of a muscle cell is to contract. It does this better than any other type of cell. But at the same time it is sensory and can conduct as well as contract. It respires, excretes, and circulates. On the whole, all these detailed processes go on in each and every cell. But, at the same time, it must not be forgotten that as specialization increases, one type of cell, now being a specialist in one type of work, has given up other types of work as far as is consistent with active life. It is doubtful whether muscle cells digest at all, but they are contractile more than anything else. It would be very difficult to demonstrate contractility in a nerve fiber.

The import of all this is, that if a general science of physiology of receptors is desired, then the most specialized organs of sense should be studied. And so with contraction, conduction, excretion, etc. In the higher animals with their special systems of organs, functions are segregated and there is a natural sorting out, enabling one to study isolated functions from this clear-cut material. The physiologist applies the common-sense method of "consulting the specialists." Therefore, the following physiological processes are described as taking place in such a highly organized vertebrate as Man.

Digestion (Fig. 313).—Proteins are nitrogen compounds of various orders of complexity. They are taken in principally with animal foods and to a lesser extent with vegetable foods. Carbohydrate foods are plant products and fats are made both by plants and animals. Inorganic salts and water taken in do not undergo much change in the body. The purpose of digestion is to change the foods taken in into a form suitable for use by the various cells. Proteins must be changed to amino-acids, carbohydrates to monosaccharids and fats to fatty acids and glycerin. The

useful parts of the food are separated from the useless and for purposes of transportation, the useful constituents except the fats are rendered soluble.

Mouth.—Digestion begins in the mouth. Here the food is mixed with saliva. This is mostly (99.5 per cent) water but contains inorganic salts, a protein compound called *mucin*, a lubricating substance and, in some animals, an enzyme, pytalin. Saliva is secreted by salivary glands. There are typically three pairs of these glands; 1st, *parotids* (near the ear), 2d, *submaxillaries*, 3d, *sublinguals*. A gland is a system of branching ducts terminating in enlarged

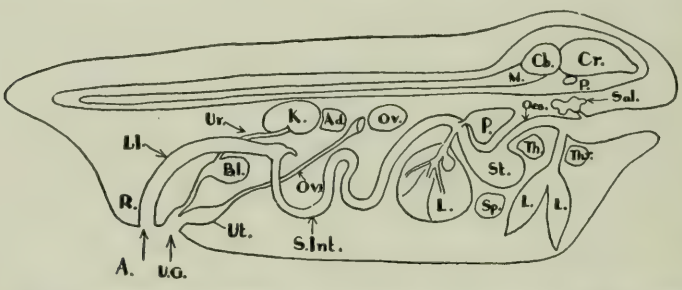

FIG. 313.—DIAGRAM OF DIGESTIVE TRACT AND OTHER ORGANS OF A MAMMAL.

Cr., Cerebrum; *Cb.*, Cerebellum; *M.*, Medulla; *P.*, Pituitary gland under cerebrum: *Sal.*, Salivary glands; *Oes*, Oesophagus; *Thr.*, Thyroid gland; *LL.*, Lungs; *Th.*, Thymus gland; *St.*, Stomach; *P.*, Pancreas; *L.*, Liver; *Sp.*, Spleen; *S. Int.*, Small intestine; *L. I.*, Large intestine; *R.*, Rectum; *A.*, Anus; *Ad.*, Adrenal gland; *K.*, Kidney; *Ur.*, Ureter; *Bl.*, Bladder; *Ov.*, Ovary; *Ovi.*, Oviduct; *Ut.*, Uterus; *U. G.*, Urinogenital sinus.

gland cells (Fig. 314). The blind end is called an *acinus*. It is surrounded by a network of capillaries and lymph spaces. From the blood capillaries, oxygen, water, inorganic salts and organic compounds pass into the lymph spaces. From these they go into the gland cells. These produce the special glandular secretions and discharge them from their free surfaces into the lumen of the acinus. The secretions pass from the various acini into the various gland ducts and eventually by a main collecting duct are poured out. In the case of the salivary glands the secretions pass into the mouth where they are mixed with the food. The production of saliva depends on stimuli such as tasting and smelling

food, chewing, sight, or even thought of good food. In certain emotional states, salivary secretion is inhibited.

Ptyalin transforms starch through several stages of digestion to maltose and this is converted further to glucose in the intestine by an intestinal enzyme, maltase.

Stomach.—Food masses passed from the mouth into the oesophagus are transferred by a peristaltic wave in the walls of the oesophagus into the stomach. A progressive moving constriction behind the food mass accompanied by a relaxation in front of it accomplishes this. Layers of smooth muscle in the walls of the stomach make possible a series of peculiar peristaltic movements, following each other every ten seconds. At the same time, it persistently accommodates itself to the amount of food inside. The larger left end (cardiac portion or fundus) maintains constant pressure on the food during all the time, while the peristaltic movements at the right end slowly churn the food. The movements of the stomach persist even if all connections with the central nervous system are cut. However, changes occur in these movements due to nerve impulses. If these pass over fibers of the *vagus* (tenth cranial nerve) violent and painful contractions may take place. Certain excitable emotional states may produce this result. Impulses over the sympathetic nerves to the stomach nerves cause an inhibition of stomach movements. The wall of the stomach contains glands which secrete gastric juice. This liquid contains from 0.2 per cent to 0.5 per cent hydrochloric acid. It also contains water, inorganic salts, mucin, rennin and pepsin. Gastric juice is obtained reflexly. The taste, smell or sight of savory food act as stimuli.

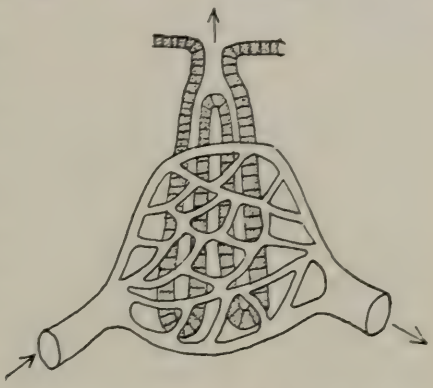

FIG. 314.—DIAGRAM OF A GLAND WITH CAPILLARY SUPPLY.

There is also a chemical control of secretion. Meat extractives present in the stomach excite secretion and are called secretogogues. Bread does not produce this result. It is supposed that secretogogues cause cells lining the pyloric end of the stomach to produce a substance called *gastric secretin* or gastrin that is absorbed by the blood and so taken to all the glands of the stomach, causing them to secrete. This gastrin, therefore, is an internal secretion which acts as a specific exciter of other cells. A general name for such a substance is *hormone*. The stomach glands secrete pepsinogen. This in the presence of hydrochloric acid becomes pepsin. Pepsin causes the hydrolysis of proteins into simpler protein compounds, the proteoses and peptones. Further digestion is completed in the intestines. Rennin coagulates milk. Calcium plays an important part in the coagulation of milk by rennin and, in the absence of calcium, coagulation will not occur. Clotted milk is retained in the stomach to permit of some degree of gastric digestion. There is also present in the stomach a weak, fat-splitting enzyme. Every now and then the pyloric sphincter opens and permits the *chyme*, partially digested contents of the stomach, to be discharged from the stomach into the intestine. A reflex nervous mechanism opens and closes this valve.

Intestine.—The first portion of the small intestine is called the *duodenum*. The duct from the pancreas pours pancreatic juice into the duodenum to mix with the food. The duct from the liver, the bile duct, pours bile into the duodenum also. Glands in the walls of the intestine secrete *succus entericus*, intestinal juice. Bile, pancreatic juice and succus entericus bring about the main digestion of food.

Pancreatic Juice is similar in appearance to saliva. Carbonates and phosphates make it alkaline. It contains the following enzymes: trypsin, amylopsin, and lipase. Trypsin, a powerful proteolytic enzyme, is not secreted by the pancreas as trypsin, but in an inactive form called trypsinogen. Another catalyst called *enterokinase* is secreted by the intestinal mucosa which activates trypsinogen to trypsin. Trypsin acts on proteins which have

been previously acted on by pepsin or on proteins which have escaped the action of pepsin and completes their hydrolysis to amino-acids. Amylopsin acts as ptyalin does. It changes starches to maltose. Maltose is further split by maltase to glucose. Lactase splits lactose to glucose and sucrase changes sucrose to glucose. Maltase, lactase, and sucrase are produced by the intestinal mucosa. Lipase hydrolyzes fats into fatty acid and glycerin. The fatty acids form soaps with sodium and potassium ions of the intestinal contents. Prior to the discovery of gastrin, Bayliss and Starling discovered that the hydrochloric acid of the chyme discharged from the stomach to the duodenum comes in contact with the mucosa of the duodenum. It causes the production of pancreatic secretin, a hormone, probably of simple organic composition. This hormone is absorbed into the blood stream and circulates throughout the body. As it circulates through the pancreas it causes this to secrete freely pancreatic juice, and in the liver it promotes the formation of bile. Since bile is also alkaline, it aids in neutralizing chyme. Bile salts are effective emulsifying agents. They emulsify the fats of the food and thus enable lipase to attack the fine particles of fat in the emulsion. Digestion of fats practically ceases in jaundice, a condition in which bile is prevented from getting from the liver into the duodenum. Digestion of fats tends to expose protein and carbohydrate particles to the digestive action of trypsin, and amylase.

The color of bile is due to two kinds of pigments, one, red is called *bilirubin*, and the other green, *biliverdin*. The bile of most herbivorous animals is green, human bile is golden brown. Bile pigments are excretions and leave the body with the feces. Cholesterol, $C_{27}H_{45}OH$, is also a waste product thrown out by the liver with the bile into the intestine and so to feces. Bile salts (sodium salts of glycocholic and taurocholic acids) are important agents of digestion as shown above. Cholesterol has a tendency at times to crystallize in the gall bladder, causing gall stones. Solutions of bile salts dissolve these. Bile is constantly secreted by the liver cells. The presence of bile in the intestine also stimu-

lates bile secretion in the liver. It is probably the bile salts that are responsible for this. They are probably reabsorbed into the blood and thus conserved for they do not appear in the feces. They also stimulate peristaltic movements. Contant peristaltic movements of the intestine serve to thoroughly mix food with enzymes and thus promote digestion. Intestinal juice contains enterokinase referred to above. Another proteolytic enzyme, erepsin, found in the walls of the intestine, supplements the work of trypsin and pepsin by converting proteoses and peptones into amino-acids.

Most of the absorption of food into the blood stream takes place from the small intestine. Water is taken into the blood from all parts of the intestine, but principally from the large intestine. There semi-fluid or solid feces are thus formed. The process of absorption is not yet understood, but a living membrane is necessary.

Proteins are absorbed into the blood as amino-acids. They pass by way of the portal vein to the liver. Blood from the liver is sent toward the heart through the hepatic vein. Monosaccharids are the only carbohydrate compounds taken up by the blood vessels. They are carried by the portal vein to the liver. Fats are absorbed by the intestinal cells into the lymph stream in a hydrolyzed form, are reunited and given to the blood in form of fat. These fats pass into the lacteals and on into the thoracic duct and so on into the heart. The hydrochloric acid of gastric juice and bile in the intestine act as sterilizing agents. The contents of the small intestine are relatively free from bacteria.

The bacterial flora increases toward the posterior end of the intestine. Bacteria probably produce enzymes which act on proteins, carbohydrates and fats, digesting these to a certain extent. Animals, such as the rabbit, have a large coecum. Cellulose stored there is broken down by the bacteria present. Bacteria of the large intestine break down proteins into simpler compounds such as skatol, indol, phenol and putrescin. They are formed by putrefaction in the intestine. They are toxic, but are conveyed to the liver which can

usually render them harmless. When there is an excessive production of them they escape as toxins into the general circulation, producing a condition known as auto-intoxication. Ptomaines are highly toxic substances produced by certain bacteria from food products. These bacteria are not normal inhabitants of the intestine, but are accidentally introduced with defective food products. Bacteria produce gases in the intestine. CO_2 and CH_4 result from fermentation of carbohydrates and H_2S from proteins.

It is probable that in many cases bacteria play no essential part in digestion. Metchnikoff was the father of the plan to rid the intestine of its usual bacterial flora by the introduction of special harmless lactic acid bacteria found in certain types of buttermilk. Feces are composed of undigested starches, meat, and cellulose. A considerable part may be dead or living bacteria, bile and inorganic salts, such as those of calcium. They should not be regarded as containing the general cell wastes of the body. Sooner or later the peristalsis of the intestine causes the accumulation of feces in the posterior end of the intestine (rectum). Its presence there acts as a stimulus for defecation. The relaxation of the anal sphincter muscle is under voluntary control, although this is an acquisition. For some time after birth it is a simple reflex.

Blood and Lymph.—Blood is a fluid tissue. It conveys substances from one part of the body to another. The average man possesses from 4 to 5 liters. Blood consists of liquid plasma in which are the white and red corpuscles. The plasma is about two-thirds the volume of human blood.

Blood clots or coagulates soon after leaving the blood vessels, either outside the body or among tissues, as in a bruise. This prevents the excessive loss of blood from small wounds. The blood of some persons does not clot readily. This condition is called *hemophilia* and is hereditary. A clot is a jelly-like mass which enmeshes the corpuscles and contracts, squeezing out the clear yellow serum. The clot is composed of a protein network called *fibrin*. Fibrin is produced from a compound called *fibrinogen*, soluble in the circulating blood. The formation of fibrin is the

result of a series of coöperating and sequential factors. Calcium salts are necessary, and, in addition, thrombin must be present. One idea is that fibrinogen+calcium salts+ thrombin=fibrin. But thrombin does not exist as such in circulating blood. It is assumed that a precursor, prothombin exists there. But this is supposed to be tied up with anti-thrombin. When blood vessels are cut, bruised or injured or other neighboring cells are injured, thromboplastin is formed. This unites with the antithrombin and frees the prothrombin, which, in the presence of calcium salts, forms thrombin and this reacts with fibrinogen to form fibrin and so the clot. Sometimes clots form inside blood vessels. This is known as *thrombosis*. If this clot is carried along in a blood vessel and lodges in a vital organ such as heart or brain it will cause death.

Plasma contains about 80 per cent water, 6 per cent to 8 per cent proteins such as fibrinogen, serum albumin, serum globulin and amino-acids, normally about 0.1 per cent glucose, 0.2 per cent fats, inorganic salts, enzymes, hormones, gases, immune substances such as antitoxins, and waste products such as urea. The red corpuscles of most Mammals are enucleated biconcave disks. The human erythrocyte is about 7.7 mm. or $\frac{1}{3200}$ of an inch in diameter. The average number is about 5,000,000 per cubic millimeter. Corpuscle number is important in diagnosis of some diseases. The important constituent of the erythrocyte is the hemoglobin. Corpuscles contain about 60 per cent water. Destruction of the corpuscles is called hemolysis. The hemoglobin when released is not functional. Hypotonic salt solutions cause hemolysis by increasing the osmotic pressure within the corpuscle. Hemoglobin with carbon-monoxide forms carboxy-hemoglobin, a more stable compound than oxyhemoglobin, on account of which illuminating gas is deadly poisonous since it destroys the oxygen-carrying power of the blood. Nitric oxide is also poisonous for a similar reason. Nitrous oxide is "laughing gas." In the disease known as *chloroanemia* the corpuscles contain little hemoglobin.

After birth, erythrocytes are formed in red bone marrow

of flat bones from special nucleated cells. After severe hemorrhage additional cells are produced. Red-blood cells have a short life period. It is thought that 5 per cent to 10 per cent of all corpuscles are destroyed daily and that they live only about ten days; also that worn-out erythrocytes are destroyed in the spleen and that their products are carried to the liver which keeps the iron to be used in new red blood cells. It is also thought that the liver may disintegrate the old corpuscles.

Normal human blood contains 7000 white blood cells per cubic millimeter of blood. Some of them resemble the protozoan Ameba in many ways such as in form, in possessing a nucleus, pseudopodia and an ameboid movement. There are a number of special types. A study of the relative numbers of these types is important in diagnosing certain diseases. Leucocytosis is a pathological condition in which there is an abnormally large number of leucocytes present, i.e., above 10,000 per cubic millimeter. Certain leucocytes engulf foreign bodies such as bacteria rendering them harmless. This is known as phagocytosis. Large numbers of leucocytes gather wherever there are infections. They pass through the capillary walls into the tissue spaces involved in the inflammation. In pneumonia and appendicitis great numbers are found. The phagocytic power varies from time to time. This is supposed to be due to the variation in amount of a hypothetical substance called an *opsonin*. Fat is carried from absorbing cells to lacteals by leucocytes. White blood cells probably have to do with the regeneration of fibrinogen after this has been reduced, and also the formation of other plasma proteins. White corpuscles are constantly formed in lymph glands and in bone marrow.

Blood is constantly giving and receiving contributions to and from the cells. In spite of this constant exchange, its physical condition and chemical composition remains remarkably constant. Its reaction is slightly alkaline (pH = 7.36). Its osmotic pressure is constant being about equivalent to that of a 0.9 per cent NaCl solution. The inorganic salts are constant in their concentration. The blood maintains about

0.1 per cent glucose all the time. There is a constancy also in the percentage of the fat and proteins. This equilibrium is very remarkable in view of the in-go and out-go, that is taking place. Between blood capillaries and tissue are lymph spaces containing lymph, a fluid something like plasma without red blood cells. Lymph is the middleman between capillaries and cells. The lymph spaces, which are everywhere, communicate with lymph vessels which convey lymph from all parts of the body ultimately to the heart. An abnormal production (collection) of lymph at any part is called *oedema*. Some substance is present in such food as crab meat or strawberries, which has a specific effect in certain individual cases. It is supposed that these foods increase the permeability of capillary walls and so cause local small oedemas to form, known as " hives." These specific substances are known as *secretogogues*.

The bactericidal power of leucocytes is increased by the injection of dead bacteria. Preparations of these in physiological saline solutions are known as *vaccines*. Inoculation with typhoid vaccine prevents typhoid fever. The presence of special antibodies is an indication of certain diseases. Such a determination is known as *serum diagnosis*. Several types of bacteria which thrive in the body produce specific poisons or toxins. But the body has a certain power of forming substances called antitoxins or antibodies which neutralize the toxin, and thus develop immunity.

If a rabbit is injected with human serum a few weeks after a previous injection, its blood pressure is lowered, its heart action weakened and breathing is labored. This resulting condition is known as anaphylactic shock. It is supposed that the first injection produces a powerful proteolytic enzyme which rapidly breaks down the protein of the second dose and these broken-down proteins are very toxic.

Circulation of the Blood (Fig. 315.)—The heart contracts and relaxes rhythmically. It contracts completely and all it possibly can at the time. The cause of this automatic beat of

the heart is unknown, but is apparently independent of nerve impulses. There are nerves present in the heart, however, whose function is stated later. A wave of contraction passes

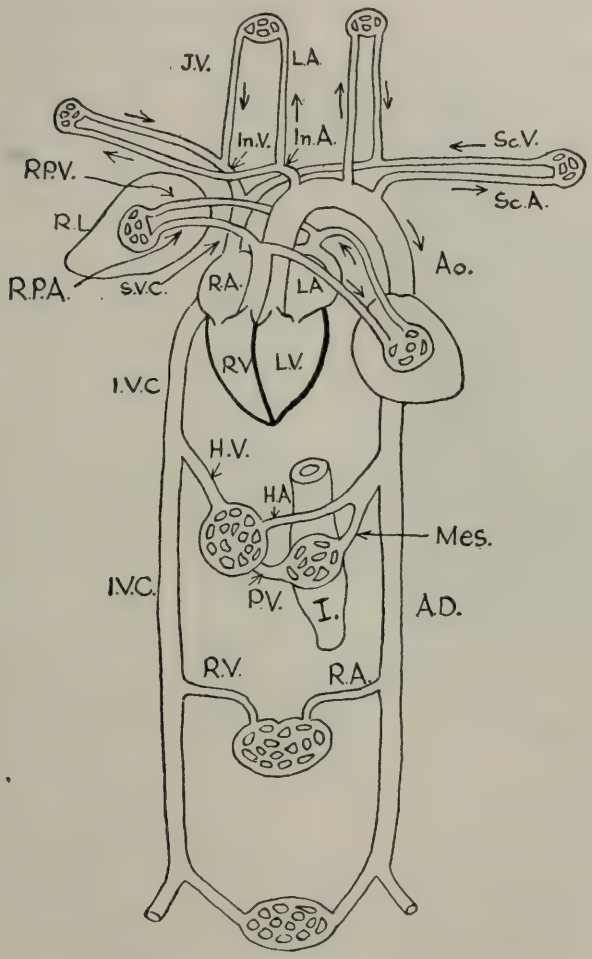

FIG. 315.—DIAGRAM OF CIRCULATION OF A MAMMAL.

R. A., Right auricle; *R. V.*, Right ventricle; *S. V. C.*, Superior vena cava; *I. V. C.*, Inferior vena cava; *R. L.*, Right lung; *R. V. P.*, Right pulmonary vein; *R. P. A.*, Right pulmonary artery; *L. A.*, Left auricle; *L. V.*, Left ventricle; *Ao.*, Aorta; *In. A.*, Innominate artery; *Sc. V.*, Subclavian vein; *Sc. A.*, Subclavian artery; *I.*, Intestine; *Mes.*, Mesenteric artery; *H. A.*, Hepatic artery; *P. V.*, Portal vein; *H. V.*, Hepatic vein; *R. A.*, Renal artery; *R. V.*, Renal vein; Below is shown blood supply to one of the limbs.

over the heart beginning at the end near the entrance of the large veins. The wave spreads to the auricles and thence to the ventricles. Sometimes the tissue between the auricles and ventricles is diseased and the normal passage of the wave is interfered with. Potassium salts in the blood favor relaxation of the heart and calcium salts favor contraction. The normal or abnormal heart beat is identified by listening to the sounds of the heart or by still more exact modern methods. *Mitral stenosis* is a disease of the mitral valve which retards flow of blood from left auricle to left ventricle. Sometimes the valve does not close tight and lets the blood flow back into the auricle. This is known as *mitral insufficiency.* Similar diseases involve the *semilunar valves* between the left ventricle and the great aorta.

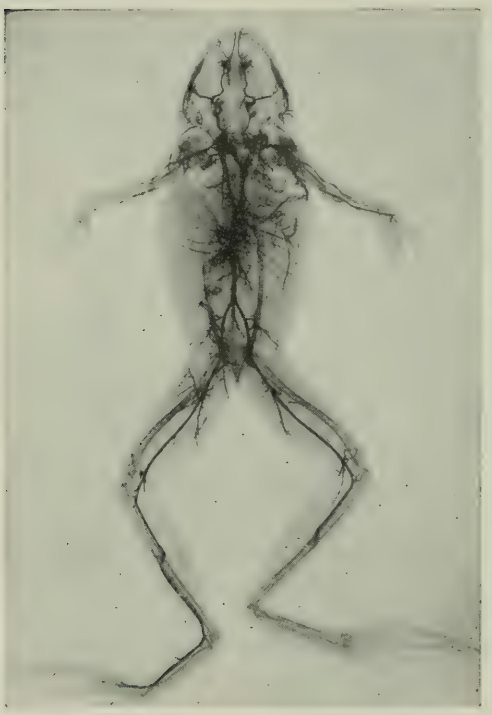

FIG. 316.—X-RAY PHOTOGRAPH OF CIRCULATORY SYSTEM OF FROG.

At each contraction from 60 to 90 cc. of blood are forced into the aorta. Contraction lasts about 0.3 second and relaxation 0.5 second. The left ventricle forces blood into the aorta with a pressure sufficient to raise a column of mercury 120 mm. to 160 mm. During the time that the semilunar valves are closed, the elastic recoil of the distended arteries serves to maintain the flow of blood. It will

readily be understood that a certain quite definite degree of blood pressure must prevail to keep the tissues supplied with blood. However, if the walls of the arteries become hardened or calcified, as is often the case in old age, there results great fluctuations in arterial pressure. One result may be the bursting of a blood vessel in the brain. The clot of blood formed there puts certain nerves out of commission and causes paralysis, if not immediate death. The normal human heart beats about 72 times per minute, that of the elephant 25 times, that of a frightened mouse is said to be 600 times. The blood makes a complete circuit in from 25 to 30 beats of the heart (Fig. 316). Nerves in the superficial regions of the heart carry sensory stimuli to the brain.

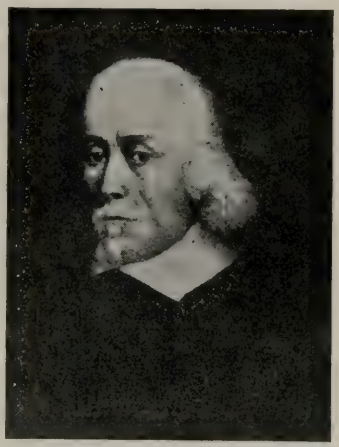

Fig. 317.—William Harvey, 1578–1667.

Discovered circulation of blood.

Efferent impulses come to the heart over the fibers of the sympathetic nerves and over the *vagus* (tenth cranial nerve). Impulses over the sympathetic fibers cause an acceleration of the heart beat while those over the vagus cause a slowing down or inhibition of the heart. Thus the heart can respond to any demand made upon it and adapt itself to varying conditions. External stimuli or emotions may change its action. The size of blood vessels and therefore their blood-carrying capacity, varies with vaso-constrictor and vaso-dilator impulses. These impulses are influenced by afferent impulses from brain or body surface to the *vasomotor center* of the brain. Blood pressure may fall, so that the brain does not contain enough blood to function. The person is pale, dizzy and may faint. If the legs and body are raised and the head lowered the brain is supplied with blood and consciousness

returns. Hemorrhage, or loss of blood, means low blood pressure. *Adrenalin*, the hormone secreted by the *adrenal glands*, causes constriction of blood vessels and thereby maintains blood pressure. It is also used in operations to decrease bleeding. The first correct idea of the circulation of the blood was developed by William Harvey in 1628 (Fig. 317).

Respiration.—In Mammals, the increase in size of the thorax at every inspiration tends to create a vacuum. This does not occur because the air rushes in through the nasal passage filling and expanding the lungs through the pharynx, through the trachea or windpipe, through the bronchi and thence through more and more finely divided bronchioles, and finally, to the air sacs or alveoli. These are minute, saclike cavities whose walls are very thin and composed of elastic tissues lined on the inside with a layer of flat epithelium. In the wall is a rich capillary network. The air does not actually rush from the outside clear into the alveoli at each inspiration, for the air in the alveoli is quite stationary. The rapid in-go and out-go has to do chiefly with the larger passageways. The movement of oxygen and carbon dioxide for the remaining distance is a matter of diffusion.

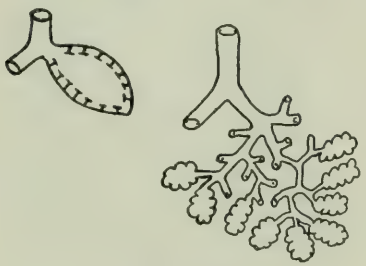

Fig. 318.

On left, diagram of lung of frog with small internal surface; Right—Part of mammal lung with great increase in surface exposed to air.

In a quadruped, the contraction of the diaphragm increases the anterior-posterior diameter of the thorax while the contractions of the muscles of the ribs increases the thoracic cavity in other directions. Expiration is ordinarily a passive act. The diaphragm muscle and tissue relaxes, this is true also of the muscles of inspiration of the ribs, while rib muscles of expiration contract. The smooth muscle and elastic tissues of the lungs contract and so the air is squeezed out. In man, there are usually from 14 to 18

respirations per minute. The respiratory epithelium of the human lungs has an estimated surface area of about 1000 square feet, 60 times the area of the body surface. The respiratory surface of an Ameba, a Hydra, or a worm is limited to the body surface area. (Fig. 318.)

A chemical analysis of in-going and out-going air reveals that important changes have taken place. This is shown in the following table:

	Nitrogen	Oyxgen	Carbon dioxide
Inspired air.....	79	20.96	0.04
Expired air.....	79+	16	4.38

There is a little change in the nitrogen. A loss in oxygen has taken place, and carbon dioxide is given out to the air leaving the lungs.

Analysis of the blood entering the lungs by the pulmonary arteries and analysis of blood leaving the lungs by the pulmonary veins reveals similar information. This is indicated by the following table, which shows the volumes of gases found in body blood before entering the lungs and also in aerated blood leaving the lungs:

	O_2	CO_2	N
100 volumes venous blood contains.....	10–12 vol.	45–50	1–2
100 volumes arterial blood contains.....	20	40	1–2

The arterial blood to be distributed to the tissues contains more oxygen and less carbon dioxide. How does this take place?

The air in the alveoli exerts a pressure of about 100 mm. of mercury. In the walls are capillaries containing blood. The hemoglobin of the blood entering the lung capillary contains about half as much oxygen as arterial blood, i.e., it is not at all saturated. Such hemoglobin when exposed to air at the pressure above named easily becomes saturated. The oxygen in the alveolus is taken up by the cells lining the alveolus, then the capillary wall cells take it up, then the plasma takes it up. The differences in gas pressure makes this possible. The hemoglobin, which is only half saturated then takes it up from the plasma. The physical aspects

of the process are apparent. In the hemoglobin of the corpuscle there is an affinity between hemoglobin and oxygen, forming oxyhemoglobin. When the blood reaches the tissues, the cells may have a lack of oxygen for they have lowered the supply in the lymph. This means a lower oxygen pressure in the plasma, and so the oxyhemoglobin breaks down giving oxygen to the plasma and thence for the same reasons from plasma to lymph, from lymph to cells. Oxyhemoglobin is ordinarily never completely reduced owing to rapidity of the circulation. Starting with an oxygen pressure of 100 mm. of mercury in the alveoli of the lungs, there is a decrease to zero in the cell.

The movement of CO_2 is just the reverse. It passes from cell to lymph to plasma. In the lung it passes from the blood of the capillary into the alveolus. In venous blood it has a pressure of about 5 per cent of an atmosphere, in the outside air it is far less than this. The CO_2 is carried in the blood in the form of sodium bicarbonate.

The problem of exchange of gases between the atmosphere and the blood and tissue cells is therefore solved by physical and chemical means. The physical laws governing gases are in operation here. Gases exert pressures. In a mixture of gases each gas acts as if it alone were present. This is borne out by the behavior of oxygen and carbon dioxide. The laws of the solubility of gases are concerned. The amount of gas that will go into solution depends on the temperature of the solvent, the pressure of the gas on it and the degree of solubility of that gas in that solvent. But solubility alone is insufficient. For it has been found that blood takes up forty times the amount of oxygen explainable in terms of solubility of oxygen in water. This great discrepancy is due to the great combining power of hemoglobin with oxygen.

The energy used in vital functions is produced by processes of oxidation in cells. The oxygen of the air combines with hydrogen and carbon of foods and forms water and carbon dioxide, thus releasing the energy stored up in the foods. The actual mechanism is not understood. These combina-

tions take place at lower temperatures than when oxidation of alcohol, gasoline, wood, or coal take place outside the body. This organic oxidation at such comparatively low temperatures is made possible by the presence of intracellular enzymes or catalysts called oxidases. Oxidative processes are governed by the needs of the tissues and not by the supply of oxygen and food available.

The problem of oxygen supply and carbon dioxide removal becomes vital. The evolution of respiratory devices alone do not solve the question. The evolution of blood and circulatory systems are just as necessary. The study of such forms as the earthworm shows that blood and blood systems are evolved before respiratory systems. The peculiar highly specialized respiratory mechanism of insects carries with it a simplified blood system. The regular sequence of inspirations and expirations in mammals is due to nerve impulses arising in a clump of nerve cells in the medulla, the so-called *respiratory center*. Destruction of this causes cessation of breathing and death. Cells are deprived of oxygen, hence oxidations cease, and this involves the heart and brain.

Normal respirations may be modified by various external stimuli, causing nerve impulses to the muscles of respiration, to depart from their normal activities. Respiratory rates may be increased or decreased. Respirations may become deeper or more shallow. A chemical control of respiration is present also. Carbon dioxide, for example, in the blood flowing through the respiratory center activates this. It has been found that this is a matter of the release of hydrogen ions in the blood. More carbon dioxide means more carbonic acid and this yields hydrogen ions, which destroy the neutral character of the blood. These hydrogen ions stimulate the respiratory center and increase the number and depth of the respirations and thus tend to get rid of the carbon dioxide and so restore the normal condition of the blood.

The air in the smallest bronchioles and alveoli is probably motionless. The exchange of gases taking place between the air in the alveoli and the air in the ducts where the air

is in motion, takes place because of the differences in gas pressure and temperature. In high altitudes the oxygen tension of atmospheric air is very much reduced. At 16,000 feet it is only about half what it is at sea level, to which, in a general sense, the animal respiratory mechanism is adapted. To supply the necessary oxygen more rapid and deeper respiratory movements are required. But these cause a diminution of the carbon dioxide of the blood. The respiratory center does not get the necessary stimulus and the whole body suffers. The heart is weak, and symptoms such as headache, nausea and dizziness show that the brain and nervous system are affected. However, adjustments usually correct this in time.

The Temperature of the Body.—The temperature of the body of most animals is only slightly above that of the air around them. As this changes, the temperature of their bodies changes. Such animals are cold-blooded. It would be very difficult to detect any difference between the internal and external temperature of a Hydra. The interior of the body of an alligator would probably be warmer than the water around it, although the alligator is a cold-blooded animal. The term warm-blooded, as applied to Birds and Mammals, is inadequate. These animals are not only warm-blooded, but are constant temperatured, i.e., in spite of variations in the temperature of the external medium, their body temperature remains about the same. The cold-blooded animals (*poikilothermic*) do not possess any temperature regulating apparatus, or, at best, a very primitive one. This suggests that the temperature prevailing during their evolution did not necessitate any regulatory mechanism. In cold weather bodily processes slow down in such animals. In fact, fishes have been frozen and, after slowly thawing out, have lived.

Echidna, the Monotreme, one of the lowest of the Mammals, is not altogether constant temperatured (*homoiothermic*). For example, when the air is changed from 5° C. to 35° C. the temperature of its body changes 10° C. In cold weather it hibernates and its body is only 0.5° C. above that of the surrounding medium. Higher Mammals (such as

the hedgehog) that hibernate, have a lower body temperature during their winter sleep.

The normal body temperature in human beings is between 37° C. and 38° C. However, it shows a normal variation of not more than 1.5° C. from this. Fever is a high temperature due to the breaking down of the heat regulating mechanism. Many body mechanisms are involved in the regulation of temperature. In warm weather we wear lighter clothing, while in the cold of winter we use more heat retaining clothing. In cold climates, houses and fires aid in maintaining a satisfactory temperature. But in addition to all these various devices, automatic mechanisms in the body are primarily concerned. The dilatation of the blood vessels of the skin (a nervous mechanism) brings more blood to the surface, where some of the body heat is dissipated. The sweat glands also secrete a watery and warm fluid. The air leaving the lungs in expirations is warmer than that entering. This air contains a certain amount of warm moisture. Evaporation of sweat from the surface of the body tends to reduce the temperature. In humid weather this is interfered with and thus the heat is retained. If the superficial blood vessels are contracted, less blood is at the surface and so less heat is dissipated. That temperature regulation is under the control of a nerve center is indicated by the fact that destruction of the vasomotor center in the medulla upsets normal body temperature relations.

Metabolism.[1]—Proteins, carbohydrates, fats, oxygen, water, and inorganic salts are taken into the living machine. They are used in various ways by the tissues and reappear as waste products which are expelled from the body. Some substances taken in and given out differ chemically. By estimating the amount of certain chemical elements formed

[1] In this book, the word Metabolism has heretofore been used in a broad sense including such processes as digestion, circulation, excretion, etc. The physiologist usually uses it to mean chemical proceses taking place in the cell. In this narrower sense it refers to processes by which simple compounds are built up into more complex compounds which is called Anabolism and also processes of Catabolism by which complex compounds are broken down into simpler compounds such as wastes of excretion. Liberation of energy attends this change. Both processes may go on simultaneously in a cell.

in each, one can obtain information as to what takes place with regard to foodstuffs in the body. To do this, the balance sheet of the intake and outgo of carbon and nitrogen and also the ratio between the amount of oxygen consumed and the carbonic acid (H_2CO_3) excreted is usually ascertained.

The chief process concerned in the chemical changes involved is one of oxidation. Lavoisier thought that oxidations in animals were similar to those in the burning of fuel. The two are in many ways alike. In both cases water is necessary and the oxidations take place by a series of steps. But oxidations in organisms occur at low temperatures. This is made possible by the presence of catalysts called oxidases. An interesting and unusual example of these is luciferase. Luciferase has been obtained in pure form from certain dried luminescent animals. This catalyst attends the oxidation of a compound known as luciferin. During the reaction light is given off but practically no heat.

In the process of oxidation in the body the energy of food fuels is released. Some of this is used in the chemical changes taking place, some appears in movements, some as heat. Energy exchange can be studied in the case of an animal as accurately as one can ascertain the energy value of a fuel like coal. The physical unit of energy is the large calorie (C). A calorie is the amount of heat required to raise the temperature of one kilogram of water one centigrade degree of temperature. The energy value of a substance is learned by burning it in a specially made steel bomb in an atmosphere of pure oxygen. The bomb is immersed in a known volume of water. The temperature of the water is obtained before and after the experiment, and the calorific value of the substance is determined by multiplying the increase in temperature of the water by its volume in liters.

By the use of this method it has been determined that oxidation of one gram of protein releases about 5 C. of heat; one gram of carbohydrate about 4 C., and one gram of fat about 9.3 C.

Carbohydrate is completely oxidized in the body and gives off the same amount of energy as in a calorimeter.

On the other hand, protein is not completely oxidized in the body. The wastes of protein metabolism are compounds which still possess a certain amount of heat energy. This can be determined and must be subtracted from the total physical heat value of proteins to obtain the physiological value of protein foods.

The energy released in animal metabolism is determined by means of an *animal calorimeter*. Calorimeters are now in use for studying energy production of animals, and also of human beings under all sorts of conditions of health and disease. The general principle is the same as that involved in the use of a bomb calorimeter. They are constructed to measure energy production to the same degree of accuracy. In one experiment performed by Benedict it was estimated that during the time involved, the human subject investigated had consumed 5459 calories, and the amount actually measured by the calorimeter was 5435 calories, which, from the point of view of the scientist, is an actual agreement. The subject of the experiment was busy at work pedaling a stationary bicycle in the calorimeter. The work performed was recorded and converted into calories and these were added to his other energy output. Another type of experiment is to determine the least amount of heat energy produced by physiological processes in a healthy person when at complete rest, i.e., asleep and a number of hours after eating. This was ascertained to be 1680 calories in the case of a person of average weight. Food taken in stimulates heat production.

A considerable amount of the energy of food is also used in muscular work. The atmosphere is colder than the body and so the body is constantly losing heat to the atmosphere. This must be made good by the intake of food. Small animals give off more heat per unit of weight than large animals because they have a relatively greater surface area. Finally in addition *first*, to the basic energy requirements for fundamental physiological needs; *second*, to the specific production of heat caused by the intake of food; *third*, to the energy needed to maintain the temperature of the body, energy is *also* needed by immature animals

for growth. They actually need more food than adults and so famine affects children the more seriously. Inorganic substances of the food furnish no energy. This comes from the organic foodstuffs.

Proteins are absolutely necessary foods. We could live on proteins alone, but it would be foolish to do so unless necessary. They are the most vitally necessary components of cells. When broken down they appear as waste substances of excretion, in the urine in such compounds as urea, and ammonia. The primary use of proteins is to rebuild protoplasm. It has been found that only about 100 grams of protein are needed in the daily diet of the average person. When excess protein is taken in, all unnecessary portions are broken down and excreted. The animal body cannot store up proteins. Proteins tend to speed up metabolism and excess energy produced is lost in heat. In diets low in protein, the body protein is saved to a certain extent if carbohydrate food is included in the diet.

Carbohydrates are the best source of energy. They are cheaper than proteins, also they are completely oxidized into carbon dioxide and water. These wastes are given off by the lungs and by the kidneys. They are thought to be not as harmful as the excess wastes involved by an unnecessary intake of protein.

In the metabolism of carbohydrates, digestion changes them to monosaccharides which pass via the portal vein to the liver. This converts them to animal starch or glycogen which is stored in the liver up to a certain amount. If an excess of carbohydrate is taken *sugar* may appear in the urine shortly after meals. This may be considered a defense mechanism. It is an important physiological fact that there is a normal level of glucose (sugar) in the blood amounting to 0.1 per cent. The muscles take up glucose from the blood for fuel. Some of it is changed into fat which is deposited in various tissues. The control of glycogen formation and its release is of the utmost importance. It has been found that a certain hormone produced by the pancreas is concerned in this process. If carbohydrate

cannot be converted into glycogen and thence fed out as needed to the blood and so to the tissues the animal cannot use it all. And, moreover, if carbohydrate metabolism cannot go on, it has been found that this affects fat metabolism also and, in time, protein metabolism. The result is that no food is of any use, and death takes place, not, however, from the same causes as in ordinary starvation, but rather from poisoning due to an unsuccessful attempt to burn other substances such as fats with the excess production of free acids. Fats are oxidized with much more difficulty than carbohydrates. They oxidize more readily when carbohydrates are being burned. There is a tendency to convert excess carbohydrates into fat.

When glycogen is plentiful in the liver, it is this which is first consumed in muscular work. If there is none of this on hand but plenty of fat, then this is burned. A fat man can live for a number of days chiefly on the fat stored in his body. If a person is starving, the glycogen first disappears, then the fat, and last of all, the protein. Life is sustained at the expense of skeletal muscles. Death occurs before the heart muscle or the nervous system is attacked.

Muscular work involves the metabolism of carbohydrate or of carbohydrate and fat. If there are no carbohydrates then proteins are broken down yielding over 50 per cent of their weight as carbohydrates. But if carbohydrate and fat are present in the food then there is no general increase in protein destruction during hard muscular work.

It has been found that a man who does not perform much physical work needs about 2600 calories of food per day, and a working man about 3000 calories. There should be about as much fat as protein and more than twice as much carbohydrate. For example, one analysis of the diet of the professional class indicated 100 grams protein, 100 grams fat, 240 grams carbohydrate, with a total fuel value of 2324° C. Tables showing the protein, carbohydrate, fat and calorific, values of our common foods are now available, and from these can be prepared varied menus of proper food values.

Vitamins.—However, it is possible to conceive of a diet, prepared from such food tables, that would appear to be

perfect in so far as the proper proportions of proteins, carbohydrates, fats, and inorganic salts are concerned, but on which animals would starve, or fail to grow, or would develop certain diseases. It is now known that the food must contain at least small quantities of certain obscure compounds which are called vitamins. This name was given by Funk, in 1911, to one of these substances because he thought that it was chemically similar to the amine bodies and that this unknown substance was necessary for life. The words "*accessory food substances*" have been suggested, but the word "*vitamin*" is coming more into general use. It is now known that at least three types of vitamins are necessary for physiological well being. The function of these is indicated in experiments, conducted on animals fed on a diet which lacks individual vitamins.

Vitamin A.—This is sometimes called *fat soluble A.* When it is absent the animal does not grow and the glands of the eyelid do not function. This leads to inflammation and infection of the eyes and possibly complete blindness. The oil glands in the skin do not function and the fur becomes rough. There is loss of appetite and so loss of weight and lassitude. There is also a high percentage of pneumonia and lung diseases. If the diet continues to lack vitamin A, death eventually occurs. It has been found in nutrition experiments that this vitamin accompanies certain fats. Cod-liver oil is very rich in it. It is also in butter, cream whole milk, and in the yolk of eggs. It is plentiful in the green leaves used as food such as spinach, clover and alfalfa. It is not plentiful in meats, and plant oils do not contain it. It is present in vegetables that contain the yellow pigment carotin, i.e., in carrots and sweet potatoes. Only small amounts are necessary. Addition of small amounts of butter, cod-liver oil or spinach to the diet corrects the conditions caused by the lack of it. It is not a nitrogenous compound. Lack of *Vitamin A* also causes *Rickets.*

Vitamin B, also called *water soluble B*, was the first to be discovered. When it is absent there follows failure of growth, lack of appetite, indigestion, anemia and emaciation. A more serious condition is general inflammation of the

nerves, leading to paralysis and death. Such a condition has long been known and has received the name *Beri-Beri.* It has occurred for ages in countries where rice is polished, i.e., the outer hulls are removed to make a better appearing and finer food. Eijkmann, in 1897, found after producing beri-beri in chickens by feeding them on polished rice, that he could cure them by feeding them whole rice or the outer hulls. This was also the experience of Funk, in 1911, in experiments on pigeons, and of Susuki in Japan at about the same time. The results are startling. Birds almost entirely paralyzed completely recover in from three to six hours. Vitamin B is not stored in the body, as is true to a certain extent of vitamin A, but must be more or less constantly present in the diet. Animal foods do not contain much of it, but apparently enough for carnivorous animals. It is more evident in plant foods, especially in yeast and wheat germs. It is also present in nuts and fruits, in the green leaves of spinach, and in the common fleshy roots of carrots and beets, and in potatoes.

Vitamin C, or *water soluble C*, is the anti-scurvy or anti-scorbutic vitamin. Lack of it results in lack of growth. Scurvy eventually appears. Some of the conditions accompanying scurvy are bleeding under the skin or from internal organs, bleeding of the gums, and soreness of the joints with accompanying great pain. The ends of bones become brittle and are easily broken. The heart is also seriously affected. It is said that of all animals studied, the guinea-pig is most susceptible to it and that next to the guinea-pig is man.

Fresh fruits and vegetables contain vitamin C. It is richest in the juices of such fruits as oranges and lemons, and in uncooked tomatoes and cabbages. It is even present in canned tomatoes. Meats are not very rich in it. Cows feeding on green grass produce milk that has anti-scorbutic power, but milk from cows that are fed on hay during the winter lacks this substance. Vitamin C is destroyed by heating or storage. Children fed only on pasteurized milk develop scurvy. Orange juice or even the juice of canned tomatoes prevents it.

It is possible that other vitamins will be discovered. Foods rich in vitamins should be employed. Recently Eddy has announced the discovery of *Vitamin D.*

Certain inorganic substances in food are also necessary. Iron, so necessary for hemoglobin, is best furnished by green vegetables in the diet. It is also found in red meats, eggs and milk. Phosphorus is also necessary in order to provide for growth of the bones if for nothing else. It is present in sufficient quantities in milk, meats, egg yolk, beans, peas and nuts. Calcium is also needed for bone formation and other purposes. For mankind the principal source of calcium is in milk. "Hard" drinking water also contains calcium in a form that can be used by the body.

A small amount of iodine is necessary. Some investigators believe that water and food supplies in certain regions do not furnish the adequate iodine supply resulting in abnormal conditions associated with the thyroid gland.

Excretion.—Excretion really begins in the various cells of the body. Wastes of cell activity are discharged from them and find their way eventually into the blood. The amino-acids of proteins are taken up from the blood by the cells. In the process of metabolism the broken down amino-acids appear as ammonia This is toxic. It is rendered harmless by the ever-present carbonic acid of the blood with which it forms ammonia carbonate. This is carried to the liver and there the ammonia carbonate loses two molecules of water, forming urea $(NH_2)_2CO$. The ammonia is thought also to neutralize other harmful acids such as lactic acid, that develop during muscular exercise. The urea is discharged from the liver along with other nitrogenous wastes into the blood stream.

Fat circulating in the blood may be used as fuel. Fat stored in adipose tissues is later taken up by the blood also. Before being burned it is probably changed to fatty acid and glycerine. By a series of physiological oxidations they are eventually changed to carbon dioxide and water. Oxidation of carbohydrate (glycogen or glucose) also occurs by a series of steps resulting in the formation of carbon dioxide and water.

The blood not only contains a fundamental structure peculiar to itself, but is also the vehicle by which oxygen from the lungs and complicated and varied compounds from the intestinal tract are carried to the tissues. It is also a vehicle by which waste products such as CO_2, H_2O, urea, etc., are carried to the organs of excretion. Here waste products are constantly being removed, although it must be remembered that the blood constantly contains waste products. Gases leave the body via the lungs or gills. Water is excreted from the lungs. The sweat glands, used primarily as part of the heat regulating system, also give off water, nitrogenous wastes, inorganic salts and gas. The liver excretes bile pigments and cholesterol into the intestine. It is known that the cells of the intestinal wall excrete inorganic substances present in excess, such as calcium or magnesium. The salivary glands, tear glands, and mammary glands may also secrete traces of waste substances.

It is the kidney, however, which is the chief organ of excretion. The vertebrate kidney is a mass of tubular glands all joining to discharge the liquid waste products by a few main ducts into a space from which the wastes pass into a ureter and from this to the outside. These tubular glands radiate out toward the periphery, not as simple straight tubes but each unit or urinary tubule is coiled. (Fig. 319.) The outer terminus is enlarged and is called a *Malpighian body*. This consists of a sac containing a network of capillaries. Portions of the nephridial tubule adjacent to the malpighian body are composed of larger cells. This part of the gland is invested with an especially rich capillary network. It is the function of these glands to remove waste substances from the blood. This may be done in part by the physico-chemical processes of filtration, and osmosis, but careful experiments show that selective secretion of the cells is concerned.

During excessive secretion of urine, an increase in oxygen consumption of kidney cells takes place, indicating activity of the kidney cells. Urea and glucose in the blood act similarly in a physico-chemical way, but urea is excreted and glucose is retained. Urine is an aqueous solution of waste

compounds, a little heavier than water and slightly acid in Man and Carnivora but alkaline in Herbivora. Eighty-five per cent of its organic wastes is in the form of urea. It contains other organic wastes such as uric acid and inorganic

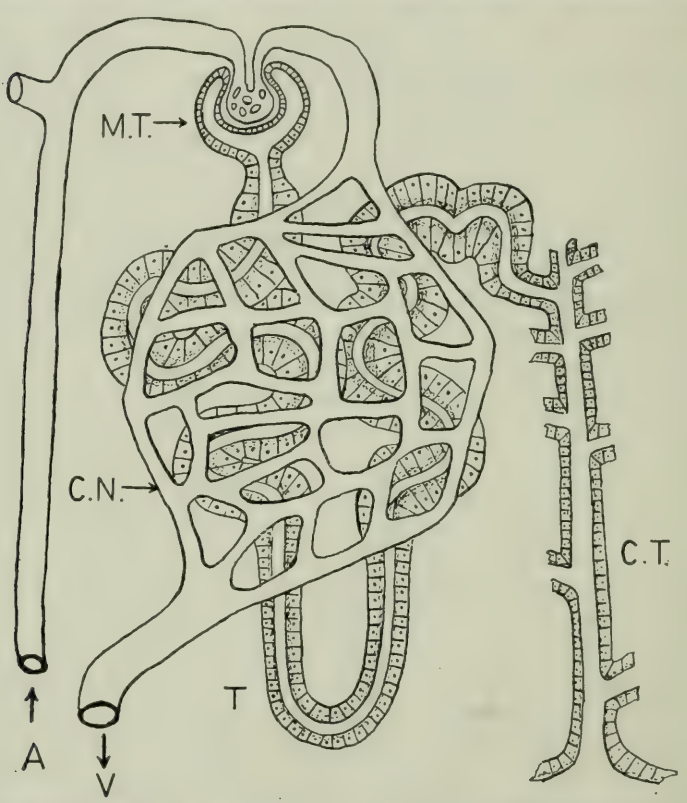

FIG. 319.—DIAGRAM OF A NEPHRIDIAL TUBULE AND ITS BLOOD SUPPLY.

A., Artery; *M. T.*, Malpighian body; *C. N.*, Capillary Network; *T.*, Part of tubule; *C. T.*, Collecting part of tubule; *V.*, Vein.

salts, chlorides, sulphates and phosphates of sodium, potassium, calcium and magnesium. When Wöhler made urea synthetically, in 1828, the barrier separating Organic from Inorganic Chemistry was broken down. It indicated that the same chemical laws operate in the living and non-living world.

Ductless Glands.—There are certain glands present in Vertebrates which secrete chemical compounds directly into the blood stream. These glands have no ducts and are therefore called ductless glands, or *endocrine organs*. Some of them are visible to the naked eye while others are seen only under the high powers of the microscope. It is entirely possible that there exist some endocrine organs concerning which nothing is known at present. Their secretions contain vitally important substances called *hormones* which control or regulate physiological processes. This means that in addition to the nervous control of physiological processes there is present a system of *chemical control* by means of hormones. (See Fig. 313.)

1. *The Thyroid gland* is located just below the larynx and in front of the trachea. It consists of a right and left lobe connected by a middle lobe. It is composed of very small more or less spherical chambers whose walls consist of a single layer of short columnar epithelium. In the cavities of these chambers is a colloid substance. Located in the substance of each lobe are two small parathyroid glands. Both these glandular structures are richly supplied with blood vessels.

Sometimes the thyroid does not develop in children. Such individuals are known as *cretins*. They fail to grow physically or mentally. The growth of the brain is interfered with. Although these persons may live for a number of years yet they remain idiotic and physically infants. If this condition is discovered early enough, the administration of thyroid extract from the gland of the sheep, for example, will entirely change the individual from abnormal to normal. The hormone necessary for growth and normal development, lacking in the cretin is supplied by the thyroid extract. It is known that iodine is concerned in this substance and a compound called *iodothyrin* obtained from thyroid glands of animals possesses it.

Sometimes the thyroid atrophies in adults and causes marked abnormalities. This is known as myxoedema. The hands, feet, face and lips become enlarged, the skin dry, the rate of metabolism decreased and deranged. The general in-

telligence is lowered. Administration of thyroid extract corrects these abnormalities due to the absence of the hormone. In some cases where the body cannot get a supply of the iodine compound from which to manufacture the hormone, an excessive development of the gland takes place. The vesicles coalesce and fill with useless colloid secretion. The gland eventually becomes an enormous cyst or tumor which can be removed surgically. This is known as *chronic goiter*. It has been found to be especially frequent in certain lake and river districts. Attempts have been made to correlate it with the absence of iodine in the food and water of these localities. *Exophthalmic goiter* is a more serious type. In this case, an excess of the secretion is produced. Metabolism is speeded up, the heart beats faster, there is loss of muscular power and development of bodily weakness, the person is very nervous and the eyeballs protrude. This is often fatal. When the entire thyroid is removed, death ensues. This is probably due to the removal of the parathyroids which are embedded in the thyroid substance. When the parathyroids are removed from a dog, convulsive contractions of the muscles follow. The animal has no muscular control. Death occurs in about ten days. Certain very toxic substances appear in the urine. There is also an unusual elimination of calcium. A certain type of convulsions in very young children are thought to be due to a deficiency of parathyroid secretion. The feeding of calcium salts results in a disappearance of the symptoms. Deficiency in parathyroid secretion results in changing the reaction of the blood to a more acid condition, and decreased metabolism of protein. In the removal of chronic (colloid) goiter, surgeons are careful not to remove the parathyroids.

2. *Thymus.*—This gland disappears after the animal becomes sexually mature. It is located at the lower end of the trachea and its function is not clearly known. Its secretions are thought to delay development of the sex organs and that removal of it, hastens their development. Some have maintained that it controls growth. Others find that after removal, growth proceeds normally provided that a proper diet is furnished.

3. *Spleen.*—This is not a gland in the ordinary sense of the word. It is a fibrous structure containing a great mass of lymph cells. Observations indicate that it produces an internal secretion or hormone which changes a pancreatic enzyme into its active form, trypsin. It is also thought to function in connection with the forming and destroying of red-blood cells. It has been successfully removed for centuries without fatal results.

4. *Pituitary Gland.*—It is located in the under side of the front part of the brain. It has three parts and it is probable that each part has distinct functions. Removal of the pituitary produces profound disturbances, but not necessarily death. When it is removed in young dogs, they fail to grow and remain sexually and mentally undeveloped. These effects are supposed to be due to the removal of the anterior lobe. Removal of the posterior lobe results in the production of a great amount of urine. This is similar to a disease called *diabetes insipidus* which is supposed to be due to an affected posterior lobe of the pituitary. Some dwarfs have very small pituitary glands. In human beings with deficient anterior lobe secretions, the individual shows conditions similar to those in which this gland was removed in young dogs. Some giants have unusually large pituitary glands. Sometimes this gland begins a sudden growth in the adult. The bones of the head, hands and feet increase greatly in size, the lower jaw develops to an unusual size and severe headaches accompany it. These changes result from an increased secretion of the gland. Some cases are benefited by surgical removal of the pituitary tumor. Administration of pituitrin, obtained from the pituitary glands of animals, helps to correct abnormal conditions produced by the lack of pituitary hormone.

5. *Pancreas.*—Located among the ordinary glandular cells of the pancreas are small clumps of cells known as the *Islands of Langerhans.* It is now known that these cells secrete into the blood a hormone called *insulin.* This is necessary for the normal metabolism of sugar in the body. When sugar is not metabolized it produces a disease known as *diabetes mellitus* which appears to be caused by a failure

of the islands of Langerhans to produce insulin or pancreatic hormone. In diabetes, the sugar absorbed from the intestine is carried to the liver by the blood. But in the liver, this sugar cannot be changed to glycogen nor stored, due to the absence of the hormone. Neither can sugar be oxidized. It is thrown back into the blood stream. As a consequence, metabolism of fats and proteins is interfered with and, due to the general derangement of metabolism, death results from *acidosis*. This is a condition in which bases are decreased due to the excessive formation of acids in the body. Powerful neutralizing devices are present in health to prevent acidosis.

6. *Adrenals.*—These are a pair of small glands near the kidneys. In man there is one just above each kidney. Their secretions (hormones) are necessary for life. When diseased, the person is physically prostrated and the condition is accompanied by vomiting. The skin becomes bronzed in color. Death follows. This is called *Addison's disease* because it was shown to be connected with a disease of the adrenals by Thomas Addison in London in 1849. When the gland is removed in animals death occurs in a few days. A hormone from one portion of the gland can be isolated in pure crystalline form. This was done in 1901, and in 1906 it was made synthetically and is sold under trade name of "*Adrenalin.*" A certain quantity of adrenalin in physiological saline solution causes the contraction of arteries. It is used therefore in checking the flow of the blood from wounds and also hastens the formation of a blood clot. There is one part of adrenalin to 500,000,000 parts of blood. Adrenalin antagonizes the action of pancreatic hormone and increases the quantity of sugar in the blood. In excitement the adrenals produce more adrenalin. As a result the blood contains more sugar. The muscles have more fuel at hand. And this means that the animal is in better condition to fight or fly as the case may be.

7. *Sex Organs.*—It has been shown that one great function of the testis is to produce sperm, and of the ovary to produce eggs. However testis and ovary produce hormones also. This is shown by the fact that when testes or ovaries

are removed from young animals, the secondary sex characters do not develop. In the male, the beard, the deep voice, the so-called " manly " form fail to develop. In the female, the mammary glands do not develop nor the sexual instincts. They reappear in a non-ovarian female when an ovary from another animal of the same species is transplanted. (Fig. 320.)

Stags, if castrated when young, do not develop antlers If castrated at maturity, the antlers are not shed annually. In the castrated cock (rooster) the male plumage changes as well as other distinctly male characters. The removal of the ovaries from ducks or pheasants results in a change from a female appearance to that of a male. Cases have occurred in which there was an unusually early development in children of secondary sex organs, at the age of six or seven years, for example. In these cases tumors of the gonads were present. Removal of the tumors resulted in a return to the normal condition. Hormone from the ovary at the time of successful impregnation of an egg causes the increased development of the mammary glands. Moreover, at the time birth occurs, they secrete milk. There is no doubt but that the gonads produce internal secretions which control the normal development of secondary sexual characters, and these are not alone physical, but mental as well.

FIG. 320.—BUFF ORPINGTON HEN THAT DEVELOPED OVARIAN TUMOR.

It had head-furnishings, plumage, and spurs of male. Its behavior was like that of a male. (From Crew, 1922).

Physiology of Adjustment

Function of Irritability. Receptors.—Ameba is irritable to external stimuli. Different parts of its protoplasm do not respectively respond to special stimuli. At the other end of the animal series, however, a mammal has many special

organs of sense and nerves, each of which is aroused by certain particular stimuli. As with all organs, a study of the comparative anatomy and physiology of animals shows a gradual evolution of special sense organs. Space does not permit of more than an enumeration of these special sense organs as they occur in higher mammals.

1. *Light.*—The sense organ in the vertebrate is the eye. The parts of the eye sensitive to changes in light are the sensory cells of the retina. Different light rays (color) and rays of different intensity produce some change in the protoplasm of the sensory cells of the eye. These cells are connected with fibers of the optic nerve. Nerve impulses are consequently aroused in these nerve fibers, which impulses pass along into the brain stimulating up certain brain cells.

2. *Sound.*—The sense organ concerned with this type of stimulus is the ear. Sound waves cause the ear drum to vibrate. Vibrations of the ear drum are communicated by the chain of three small bones in the middle ear to the membranous window (*fenestra ovalis*) between the middle ear and the inner ear. On a spiral shelf of the membranous inner ear are thousands of sensory cells (of hearing) immersed in a fluid in the membranous cochlea. Vibrations of the fenestra ovalis sets up vibrations in this inner fluid (*endolymph*). Certain vibrations stimulate certain sensory cells. The nature of the endolymph vibration depends, as is evident, on the nature of the external sound. Once these sensory cells are stimulated, the momentary change produced in their protoplasm is communicated to the nerve cells with which they are connected and so particular nerve impulses pass over nerve fibers forming part of the eighth nerve to arouse certain cells in the brain.

3. *Equilibrium.*—When the body, or especially the head, changes its position in any way, certain brain cells are aroused and thus the body is aware of the change in position. The external sense organ involved is not only that of the eyes but also the semicircular canals associated with the auditory apparatus. There are three of these membranous canals or tubes in each ear. One is horizontal, two are vertical to this and at right angles to each other, as shown

in the diagram. Each semicircular canal possesses an enlargement known as an ampulla and in these ampullae are sensory cells. The canals are filled with endolymph and in this endolymph are fine calcareous particles. Suppose the head falls forward. Then certain cells on one side of this apparatus will be stimulated. Impulses pass at once from these cells over nerve fibers to appropriate cells in the brain. Suppose the head is erected again, then other sensory cells are stimulated. If the head falls to one side then certain other cells will be stimulated. So the animal is constantly informed of its position.

4. *Odors.*—In the mucous membrane of the upper back part of the nasal cavities are sensory cells, which are stimulated by odoriferous particles given off into the air by certain substances. These sensory cells of smell are connected with fibers of the olfactory nerve, and hence impulses are carried to cells in the brain.

5. *Chemical.*—On the tongue and back part of the mouth are located special and various sensory cells which are stimulated by certain components of the food in solution. These taste cells occur in special organs. Impulses aroused in this way in these sensory cells of taste are carried by certain nerve cells to certain other nerve cells in the brain.

6. *Touch.*—The contact of external objects with the surface of the body stimulates certain sensory organs located in the skin. These impulses aroused pass on to certain nerves and from these to certain nerve cells in the brain. There are over 500,000 such sense organs distributed over the surface of the body. They are closer together at some places than others and so some portions of the skin are more sensitive than others. The tip of the tongue is most sensitive, while the back of the neck is least sensitive.

7. *Muscles.*—When weights are held in the hand, or when parts of the body support a weight, then the consequent contraction of certain muscles involved in supporting the weight stimulates end arborizations of certain nerves, with the result that appropriate impulses are sent over these nerves to cells in the brain. Thus we are not only aware of

differences in weight of objects, but what is more useful and usual, we are constantly informed of changes in the muscular system. That is, we are aware of our muscular movements. This muscle sense works with the sense of equilibrium and vision in making locomotion possible.

8. *Pain.*—There is evidence that, widely distributed over the body, are special nerve endings which are aroused by injurious stimuli. The sensations aroused in the brain are those of pain.

9. *Heat and Cold.*—Two special groups of end organs distributed like points throughout the surface of the body are stimulated by changes in the temperature of the external medium. The so-called heat spots are stimulated by temperatures higher than that of the skin, while the cold spots are stimulated by temperatures lower than that of the skin.

10. *Hunger.*—This is an ill-defined sensation aroused by lack of food. It is natural to associate it with the stomach. It is now known that, accompanying hunger pains, there occur violent contractions of the wall of the stomach, so that the sense organ of hunger may be regarded as consisting of ends of sensory nerves located in the stomach. These sensations inform the individual that the cells of the body need more food.

11. *Thirst.*—When very thirsty, we note a feeling of dryness in the membranes of the throat and pharynx. This sensation informs the individual that the body cells generally need more water for the chemical changes incident to life.

12. There are a great many other kinds of sensations aroused by a variety of stimuli. Although special sense organs and conducting nerves are not known, yet it is believed nevertheless that some sort of apparatus must be present to carry out these functions. The feeling of fatigue, sexual feelings, and the sensation of nausea are examples of these; the vague feelings of well being or malaise are other examples. All these structures in which sudden changes in the conditions of the environment produce changes in certain definite portions of their protoplasm are called *receptors.* They are sentinels in the front-line trenches. In some cases

special epithelial cells are arranged in special sense organs, in others the end of a nerve has to suffice and this is probably not as sensitive as the first. If we stimulated the sensory cells of the eye with a small object directly, we probably would "see" a flash of light. But it would all be quite useless to us. Each type of receptor is specialized to react best to its own appropriate stimulus, i.e., it is selective. Sound waves beat against the skin, but the skin is not affected by them.

Function of Conduction.—Protoplasmic changes produced in receptors are continued along definite conducting organs called nerves. The superficial protoplasm of the Ameba is receptive, but the change in it is carried into the deeper protoplasm, and the Ameba responds by some sort of contraction. In the study of Hydra we showed indications of the early appearance of special structures for each of these functions of adjustment. There are two muscles of the upper arm concerned in bending movements of the forearm. In front of the upper arm is the biceps muscle. Just opposite it on the other side is the triceps. When we flex the forearm against the upper arm, the biceps contracts and the triceps relaxes. This shows that the bending of a part of the body involves the contraction of certain muscles and relaxation of others. Or, one is a case of excitement while the other is a case of inhibition. A certain drug, strychnine, injected under the skin of a live frog upsets all normal muscular coördination. On the slightest stimulus from without all the skeletal muscles of the frog contract simultaneously and the body and the legs are stretched out in a convulsive rigidity making locomotion impossible. It is hard to conceive of locomotion in any animal where contraction of one part is not compensated for by relaxation in another. This is true even of the Ameba. While the protoplasm of one part of the Ameba's body is contracting it is relaxing at another part.

1. *Nervous System.*—In the higher animals this coördination is accomplished by the nervous system. The nervous system, we have seen, has evolved from the generalized condition seen in lower animals like the Coelenterates and Flat-

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worms to the highly complicated nervous systems of a Vertebrate and finds its highest expression in man. The nervous system not only is concerned in bringing about proper muscular contractions by which the skeletal levers act so as to move the animal either toward or away from certain stimuli, but it regulates the activity of certain vital internal organs. For example, modifications in the rate of the heart beat, and the regular rhythm of respiration are under nervous control. That part of the nervous system that in a sense lies outside of the central system, the so-called sympathetic, has nerves which follow the blood vessels. It forms a network or plexus of nerves about the stomach, heart, intestines, and kidneys. It controls involuntary or smooth muscle. We have already shown that certain physiological processes are also under the chemical control of hormones. The central nervous system is somehow changed by repeated stimuli of the same sort. The cells of the brain become modified. Although we do not know the anatomy involved, yet there is no doubt that memory has some neurological basis. Moreover, the appearance of memory leads to possibility of making generalizations and so rational thought comes into existence. Discussion of such matters is beyond the scope of this volume. It should be kept in mind that reason, and the appreciation of art and even the knowledge of right and wrong, are all in a sense physiological and have a morphological background. It is possible here to present only a brief picture of the anatomy and physiology of the *nervous system.*

The simple apparatus of mediating irritability and contractility of a Hydra soon appears in higher animals as a definite mechanism called a *reflex arc.* This in its simplest form consists of three parts: (*a*) *receptor;* (*b*) *adjustor;* (*c*) *effector.* These are physiological rather than anatomical terms. An anatomical picture gives a clearer explanation of just what is meant by it. Among the cells of the skin is a sensory or afferent nerve cell. This is not only a receptor, but the impulse aroused passes over its axone to a central organ, such as a ganglion in the nerve cord of the earthworm or to the spinal cord of a Vertebrate. In most

cases, as shown in the description of the receptor system, special sense cells (of the sense organs) are acted on by the stimulus, and these sense cells are connected with afferent nerves.

The sensory or afferent impusles pass over connecting nerve branches (*synapsis*) into a motor nerve cell body. It arouses an impulse in this cell and the impulse continues out (efferent) over its axone. This is the adjustor part of the reflex mechanism. The impulse is carried out over the *motor cell* neurone to a muscle (effector) causing a chemical change in the muscle which is expressed by a contraction. Nerve impulses pass over axones in one direction; over sensory nerve axones toward a nerve center; over motor nerve axones outward toward a muscle. The nervous system of Vertebrates is made up of a great many; some relatively simple and many complicated reflex arcs.

A simple type of nerve center is illustrated by the ventral ganglia of the nerve cord of the earthworm. There is a double one of these in each segment. In Arthropods a larger ganglion is found in the head above the oesophagus and larger ganglia in the thorax. These are formed apparently by the fusion of the lower segmental ganglia. The brain of Vertebrates is analogous to the head ganglia of the Arthropods. But the large vertebrate brain contains many nerve centers and is an organization of many ganglia. The nerve cord of a Worm, an Arthropod and a Vertebrate not only contains nerve cell bodies in ganglia, but the portions of the cord between the ganglia contains nerve fibers or *axones*. These serve to connect the ganglia. This does not necessarily mean that ganglion No. 3 is connected with No. 4 alone; and No. 4 with No. 5. For some axones of head ganglion may pass down along the nerve cord to ganglion No. 2, others to 4, others to 7 and so on. A stimulus applied to a spot on the skin of the earthworm may arouse impulses which pass into a certain ganglion. But from this it may spread to adjacent ganglia so that more than the muscles of the segment stimulated may be affected. If the stimulus is strong, impulses may be sent up to the head ganglion and the whole body may be aroused.

The nervous system of a Vertebrate may be thought of as consisting of thousands of pathways or nerve tracks along which sensory impulses, aroused by this or that form of stimulus, pass into the central system to the higher centers in the brain, and also of thousands of tracks of neuraxones over which motor impulses pass from the higher centers out to muscle or gland. The nerve tracks involved may consist of a chain of nerve cells. Another complication consists in the fact that although the activities of lower animals may at times appear to be a mass of reflexes, yet only too often they are not all simple and machine-like as the extreme mechanist would claim.

One afternoon the writer observed a wasp dragging a very much larger black spider over the ground. After proceeding laboriously for about fifty feet the wasp encountered a pile of stones. In the attempt to pass this obstruction the spider was dropped far down between two stones. The wasp flew about, then returned, and in a few moments reappeared dragging its prey successfully to the other side of the barrier. To say that this series of movements is merely a succession of complicated reflexes would be an incomplete explanation.

In man, moreover, some incoming impulses are referred to higher centers which somehow block the reflex response. Memory or better judgment, we say, urges delay or caution. The nervous system is composed of many millions of cells and it is a reward of the long arduous labors of neurologists that their work has been crowned with the discovery of some idea of order underlying this great complexity. In the Vertebrate a slight skin stimulus arouses a receptor in the skin. A nerve impulse passes over the sensory nerve cell to the sensory cell body in the ganglion on the posterior root of a spinal nerve. The impulse continues from this via the posterior root into the posterior horn of gray matter of the spinal cord (Fig. 321). (1) The nerve fiber involved may pass around in the gray matter of the same side and connect with a motor cell in the anterior horn. In this case, a motor impulse would pass out along its axone in the anterior horn, and out in the

same spinal nerve and end in a muscle directly under that portion of the skin stimulated, (2) or the sensory nerve cell spoken of, may also join with an intermediate neurone which extends for some distance up or down the cord in its white matter and has branches which connect with motor nerve cells at several levels of the cord so that motor impulses may go out over several spinal nerves, (3) or motor cells on the other side of the cord may be affected as well; (4) or this sensory nerve cell spoken of may connect with a cell whose axone extends up the cord to the medulla. Here it connects with other neurones which carry the impulse higher up. For example, it may connect with neurones whose axones extend up to the cortex (outer rind of gray matter) of the cerebellum, or it may go up to a center in the brain, and from this to the cortex of the cerebrum. (Fig. 322.)

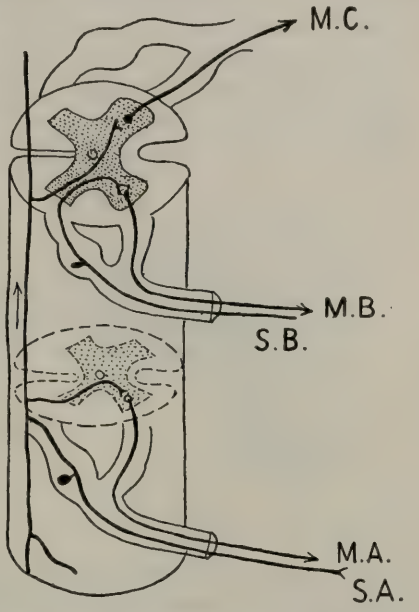

FIG. 321.—DIAGRAM SHOWING REFLEX ARCS IN SPINAL CORD AND MOTOR AND SENSORY PATHWAYS. SENSORY CELL *B* CONNECTS WITH MOTOR CELL *B* AT SAME LEVEL FORMING A REFLEX ARC.

Note connection between sensory cell *A* and motor cell *A*. But sensory cell *A* also continues up the cord and also sends a branch across to the opposite gray horn, connecting with motor cell *C*.

The spinal cord, therefore, consists of a segmental series of lower and reflex centers. It is also a highway over which stream two sets of impulses. Over fibers lying in posterior region of the cord (sensory) impulses stream upward toward the brain. Over fibers lying in the anterior region of the cord motor, impulses are streaming down the cord, some passing out over spinal nerves at this level and others at another level.

2. *Medulla.*—Some afferent impulses end in the medulla and are there shunted off into motor impulses. The medulla is an automatic center of the most vital sort. It regulates heart action, it controls respiration and the contraction of the blood arteries and, therefore, has a great deal to do with blood pressure, so important in all physiological activities. It is the control center of such simple reflexes as winking, chewing, swallowing, vomiting, sneezing and coughing. It is also a relay station from which afferent impulses are continued on up to the brain, and from which motor impulses from the higher centers are sent on down the cord.

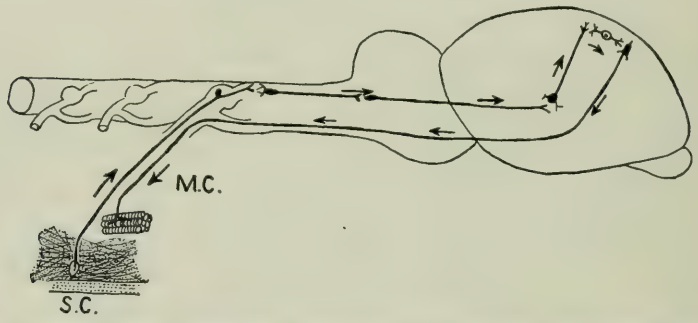

FIG. 322.—DIAGRAM SHOWING PATHWAYS IN CENTRAL NERVOUS SYSTEM

Sensory cell *S. C.* continues into the cord and connects with a neuron extending up to the medulla; thence to sensory center in cerebrum, thence to cortex, thence by association cell to motor cell in motor area, thence by axone down the cord to a muscle.

3. *Cerebellum.*—This is relatively larger in man and apes than in other Vertebrates. Experimental evidence and observations on human beings with a diseased cerebellum indicate that the cerebellum is not an organ of intelligence but governs the coördination of muscular movements, especially those concerned with locomotion. For example, a pigeon from which the cerebellum has been removed cannot fly or walk. It tumbles over. Dogs thus operated on behave similarly. They may recover partially in time, but this is because a coördinating mechanism of a sort is set up in the cerebrum between the eyes and limb muscles. (Fig. 323.) The result is similar if there is injury to the sensory organ of equilibrium, namely the semicircular canals.

4. *Cerebrum.*—The brain consists of an outer rind or cortex of gray matter in which are located nerve cell bodies. The convolutions and fissures increase the area for location of these cells. From these, axones extend down into the interior, and other axones from centers in the interior pass up to the cortex. Association neurones connect one part of one side of the cortex with another portion of the same side. Commisural neurones connect one hemisphere of the cerebrum with the other. The brain is not a solid mass, but contains cavities or ventricles which can be traced back to the spinal canal of the embryonic nerve cord. The *optic*

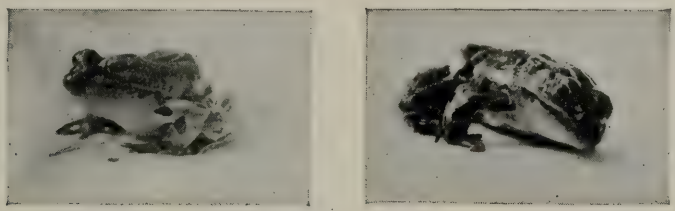

Fig. 323.

Note the posture of the normal frog at the left. In the right frog, the sensory organ of equilibrium of the right ear is non-functional. The head is turned to the left. (Photos by Fread.)

thalami are a pair of large internal ganglia or nuclei which receive impulses from neurones extending into them from centers in the medulla. These sensory impulses pass up over other neurones to the cortex. Motor impulses arising in the cortex pass down over certain groups of fibers to motor centers in the interior, and from these over other neurones to centers in the medulla, and from this possibly down the cord to the sciatic nerves and down to the toes.

A dog from which the cerebrum has been removed (and in one case the animal survived for a year and a half) breathes, walks, runs and swallows if food is placed in its mouth. It is a mere automatic machine. It has no memory, no fear, no feelings. A similar experiment on a series of Vertebrates from lower to higher indicates the increasing importance of the cerebrum as one goes " higher " in the scale. There are two chief fissures on the outer side of each

hemisphere. One of these, the *fissure of Rolando*, begins at about the middle of the upper surface and extends downward and forward. The *fissure of Sylvius* is on the lateral face of the hemisphere and extends from in front toward the rear. The frontal lobe of the brain is above the fissure of Sylvius and anterior to the fissure of Rolando. The *temporal lobe* is below the fissure of Sylvius. The *parietal lobe* is behind the fissure of Rolando. The *occipital lobe* is most posterior of all, being behind the parietal and temporal lobes.

By various lines of evidence it is known that the cortex has a geography of its own (Fig. 324). In apes and man, the cortex just in front of the fissure of Rolando contains motor neurones which control the movements of the body. There is evidence also of an orderly distribution. Beginning with the upper reach of this region and passing down and toward the fissure of Sylvius occur: (1) neurones which control the movements of the legs; (2) lower down, neurones which control movements of the trunk; (3) cells which control the arms; (4) cells which control facial muscles. (5) On the left side near the cells which control the movements of the hands are probably special cells controlling the writing of words. (6) Near the face and tongue center on the left side are probably cells controlling speaking of words.

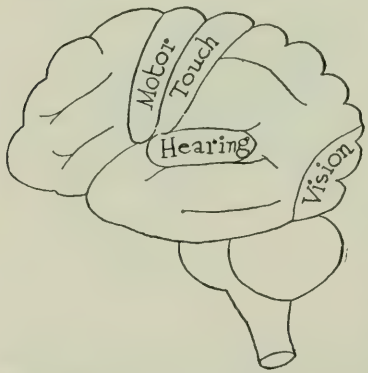

FIG. 324.—DIAGRAM OF LATERAL VIEW OF HUMAN CORTEX SHOWING SENSORY AND MOTOR CENTERS.

In the back part of the occipital lobe is a region containing cells which control vision. This is called the *visual center*. On the side of the hemisphere just below the back end of the fissure of Sylvius are cells which control hearing. This is the *auditory center*. Associated with both the visual and the auditory centers (on the left side) are probably

cells which are associated with reading words and hearing words. In the cortex on the inner face of each hemisphere are the *centers for smell and taste*. Just back of the Rolandic fissure is the cortical center of cutaneous senses. It is marked "Touch" in the diagram.

This is true of the other centers. Observations of certain kinds indicate that the frontal lobes in front of the motor center are the centers of intelligence, ideas, memory, judgment and will. Notwithstanding the fact that the function of a large part of the cortex is not known, it is remarkable that such a considerable part of its area is so definitely known.

The cerebrum is a central office to which a multitude of messages concerning the external world is referred. Messages received via the eyes, ears, nose, tongue, skin and muscles are for the most part relayed to it. In the normal brain this does not result in confusion but all is order. These impulses arouse some change within. It is possible that the response will be immediate and may involve many motor outlets. If this is necessary the apparatus is well equipped to make a complicated response, because of the property of coördination which the brain possesses. It is also possible that there will be no response, for the brain is somehow equipped to sidetrack and inhibit incoming messages.

The brain is able to record and store previous messages received and also its reactions to them. The conduct of the individual may be either immediate response or no response. But this is already getting beyond the boundaries of pure biology. It is the duty of the psychologist to explain further.

Contraction.—Animals provided with a skeletal framework to which striated muscles are attached are capable of more active movements than such animals as the earthworm without such a framework. The bones serve not only as a central support to which the central ends of the muscles are attached, but the outer ends are attached to levers forming the skeletal features of fins or limbs. These muscles (striated) are provided with sensory and motor nerves.

Muscle sense organs are located in the muscle. When the muscle contracts, these sense organs are excited and a sensory impulse is sent to the central organ which thus receives information of the condition of contraction and from the mass of such information the animal is able to judge of its position and progress.

On the other hand, motor impulses coming from the central organ to the muscles cause them to contract. Levers are moved in a certain orderly way, and thus locomotion is possible. The muscles of the locomotor organs are arranged in pairs so that when one muscle contracts another relaxes. All the work is carried out usually in a coördinated fashion. If this were not the case no progression of the body would be possible.

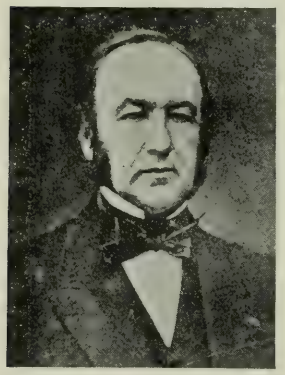

FIG. 325.—CLAUDE BERNARD, 1813–1878. EXPERIMENTAL PHYSIOLOGIST.

Muscles are naturally elastic. In the living animal they are always partially contracted and it is known that when they have to actively contract, this preliminary state of partial contraction is advantageous. The amount of contraction depends on the degree of stimulus up to a certain maximum stimulus, beyond which greater stimuli do not produce any greater contractions (Fig. 325). Heat increases the height of contractions of isolated muscles and also increases the speed of the contraction, while cold has just the opposite effect. Chemicals and drugs modify normal contractions. Potassium salts depress and calcium salts excite. Caffein and strychnin are stimulants of cardiac muscle.

Muscles fatigue after repeated contraction. Their store of fuel is consumed and, in spite of more being carried to them by the blood, a change has taken place, rendering this ineffectual. The blood is also flushing out waste products and the inability of the muscle to continue to contract is probably due to the accumulation in it of waste

products. It is believed that the chief fatigue substance is a form of lactic acid peculiar to muscle and called *sarcolactic acid.* Rest is necessary to enable the muscle to return to its normal condition. Anything which favors the carrying away of fatigue products assists in the recovery from fatigue. Taking on of additional fuel does not necessarily help the condition. Warm baths speed up circulation in the muscle. Water taken internally is taken up by the blood and so carried to the muscles and aids in the removal of wastes of catabolism. Muscle fuel has been mentioned. *This is carbohydrate food.* In the blood it is present in the form of a monosaccharid, glucose.

It has been found that furnishing cane sugar to soldiers on a hard day's march is an aid to keeping up the march. What probably happens is that the cane sugar is easily changed to glucose in the intestine and is soon supplied to the muscles. Meat is not a good fuel because it is largely protein. As such it is useful chiefly in replacing worn-out protoplasm of muscles. But surprisingly little muscle protoplasm is broken down in muscular activity. The great fuel supply is carbohydrate. It is often thought that fatigue is due to the nerves being broken down. Ordinary muscular fatigue is due, however, to muscle deterioration and not to changes in the nerves. This does not mean that nerve centers are not fatigueable. The amount of energy produced by an active muscle that is available for work compares favorably with the best engines invented by man. In both cases most of the energy (roughly 75 per cent of the fuel involved) is dissipated in the form of heat.

It must not be forgotten that the muscles of the trunk, though apparently not taking part in locomotion, yet do play a necessary part. Certain of these muscles move the head. Others assist in keeping the body erect. Others assist in chest movements necessary for respiration.

In addition to the muscles attached to bones and used in locomotion, important muscle of another type is found in the wall of the intestine, of the blood vessels, of the ureters, bladder and oviducts. This is *smooth muscle.* Its physiological properties are similar in nature to those of striated

muscle. However, it reacts to stimuli much more slowly and it is not under the control of the higher centers, i.e., it is said to be involuntary. This muscle is essential to the circulation of the blood, to the functioning of all the glands, to respiration, to the movement of foods through the intestine, and to digestion. It is as vitally important as *striated muscle,* which is concerned with physiological processes of adjustment to external stimuli, while smooth muscle takes part in this also in furnishing the striated muscles with blood. Smooth muscle is more actively concerned with those processes which we termed metabolic.

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CHAPTER XXVI

DISTRIBUTION OF ANIMALS IN SPACE AND TIME

Living organisms are widely distributed. Distribution in *time* will be discussed under the heading "Palaeontology." Distribution of living animals in *space* can be studied from two points of view: *Geographic*, or surface distribution, and *Bathymetric*, or altitudinal distribution.

Geographic Distribution.—Life exists everywhere—in the tropics—in the arctics—on mountains—in valleys—in deserts. But the Fauna and Flora are not evenly distributed. Peculiarities are common. Africa has the gorilla, chimpanzee and elephant, while Brazil, with conditions similar to those of Africa, possesses the tapir, the sloth, and the New World monkeys. Tapirs, however, also live in the Malay Peninsula. Why does not the tiger inhabit America? Why are the Marsupials the prevailing Mammals of Australia? The peculiarities of present-day geographical distribution of animals and plants present many problems. Bartholomew states that the solution of such problems involves a complete knowledge of animal life, and classification by the natural method, in which the theory of evolution is the guiding principle. Then together with distribution in space, a knowledge of palaeontology and geology is necessary. There is much evidence to indicate that certain animal forms at some time began to develop in a certain center. They multiplied rapidly, food became scarce, and thus migration automatically followed. Changing climatic conditions may have compelled this. If migration was not possible the form may have entirely disappeared. How far can animals wander from the original home if favorable conditions are encountered? Is migration prevented by barriers? By what means is dispersal effected?

A study of barriers demonstrates their effect on geographical distribution.

Mountains.—High and long mountain ranges, especially if they prevent the north and south migration of animals, act as effective barriers. The Himalaya Mountains, extending in a general east and west direction north of the equator, have a distinct tropical climate and related Fauna on the south and to the north a climate and Fauna of a very different type, and in many respects like those of Europe. Mountains running north and south do not produce such effects. They may be so situated, however, as to affect in other ways the Flora and so the Fauna. The mountain ranges in the Western United States extend parallel with the Pacific coast line. Moisture-laden winds from the ocean blow east, meet the mountain barriers, and are deflected high into the cold upper air which precipitates the moisture so that dry winds sweep over the land east of the mountains. This country is desert or dry plain and vegetation is meager. Here herbivorous animals are scarce and their absence means fewer Carnivores. The great Mexican plateau, although geographically in the tropics, has a temperate climate and Fauna. The edge of the plateau descends abruptly to lower altitude where tropical climate and Fauna prevail. (Fig. 326.)

Climate.—Heat and cold does not greatly limit the distribution of warm-blooded mammals. The tiger is at home in the hot climate of India, but wanders up into snowy slopes of the Himalayas. It is also found as far as 53° north latitude in Siberia. The African and Indian elephants also appear to withstand extremes of heat or cold. Conversely, cold retards metabolic processes in Reptiles and Amphibia, and they are most numerous in the tropics, decreasing in number toward the poles. Hibernation is an attempt toward adjustment to colder climate, but, in spite of this adaptation, their range is far more limited than in the case of Mammals. Deserts prevent migrations of Amphibia and even large Mammals. Deer, for example, are absent from Africa because they cannot cross the Sahara Desert. Not only lack of moisture affects migra-

tion, but also increased humidity may keep out animals not adapted to swamp life.

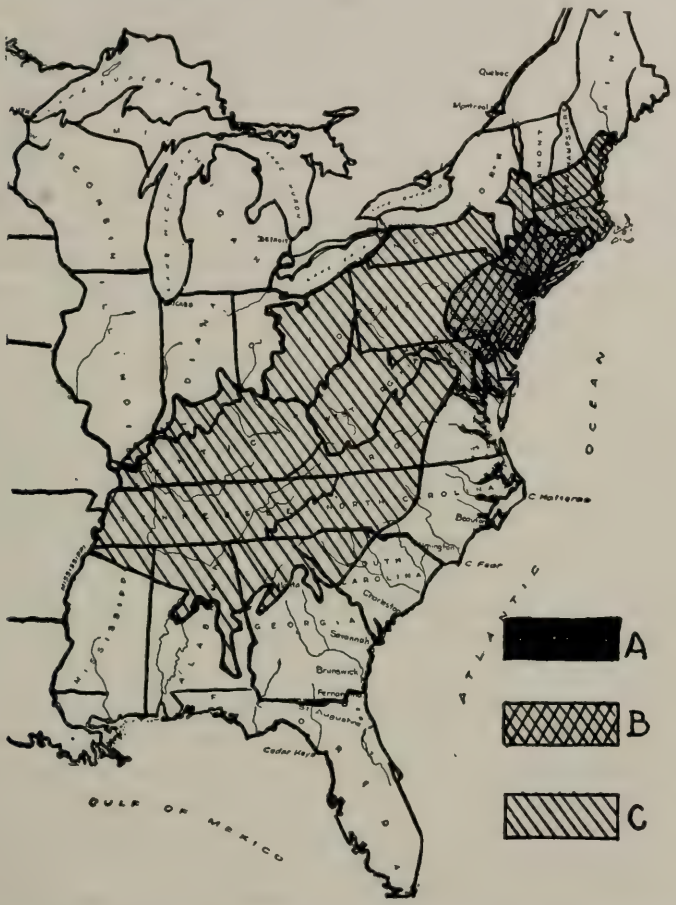

FIG. 326.—MAP SHOWING DISTRIBUTION OF A NEWLY INTRODUCED SPECIES.

Spread of the chestnut blight. Started in New York in 1907 (*A*) spread to New England, New York, New Jersey, Delaware and Pennsylvania by 1913; (*B*) Now it has spread to all the shaded areas (*C*) where chestnuts grow. (From Schlock in McIlvain's *Lumber News.*)

Vegetation.—Impenetrable jungles are impassable for large animals like the elephant. Primates which live in forests could not live in treeless countries. Animals which

feed on green leaves and stems could not exist in a country where these are absent. Moths and butterflies are restricted to areas producing flowering plants. Plant-eating insects cannot live where their particular food does not grow. Insectivorous birds are not to be found where their particular insect food cannot be obtained.

Land and Water Barriers.—Seas and oceans prevent migrations among forms with weak powers of aquatic locomotion. Amphibia, snakes and lizards cannot get from the mainland to oceanic islands if large water areas exist between the two. The giant tortoises of the Galapagos Islands, six hundred miles west of Ecuador, appear to have been stranded there. Fossil remains of similar forms are found on adjacent continents. These tortoises are poor swimmers. All the facts indicate former land bridges connecting these islands with the mainland. Bodies of water do not act as barriers to birds and winged insects. Winds favor their flight. Land Mammals cannot traverse great bodies of water. Cape Cod acts as a land barrier thrust out into the sea for many miles. The waters of Massachusetts Bay are much colder than those south of Cape Cod, and this is reflected in differing marine Fauna in the two regions. Many of the marine Invertebrates and Fishes are so constituted as to be unable to exist in fresh or even brackish water. This is especially true of starfishes, sea urchins, squids, corals, and sponges. The few fresh-water sponges have no skeleton. A few so-called Anadromous (up-run) fishes can pass from salt to fresh waters to breed. Salt water is especially toxic to Amphibia. Great migrations of animals have taken place of necessity. A land bridge connected North and South America up to the Mid-Eocene period. This permitted animals to wander back and forth as often as necessary. These migrations ceased during the disappearance of this bridge from the Middle Eocene to Early Pliocene. Then migrations began again. All of this is shown by palaeontological evidence. Behring Strait formerly existed as a land bridge over which there was a constant procession of animals back and forth between America and Asia. Animals are carried long distances on driftwood. Often collections of debris, forming

natural rafts, break away from the shores of rivers and are carried away, possibly hundreds of miles, over sea to distant shores bearing with them animals of one sort or another. Large snakes and Mammals have thus been transported. It is quite certain that moths, aided by favoring winds, have been successfully transported over a thousand miles of ocean.

African elephants migrated all over the world in times gone by. American camels and horses migrated to Asia. Migrations of many animals is a yearly occurrence at the present time. As zoologists classify animals into phyla, classes, orders, etc., so the student of distribution divides the earth's surface into realms, regions and provinces. These are determined by the presence or absence of certain animals. Lydekker divides the whole earth's surface into three realms; (1) *Arctogoea*, North Land, which would include North America, Europe, European Asia and Africa; (2) *Neogoea*, New Land, South America, part of Central America and West Indies; (3) *Notogoea*, South Land, consisting of Australia, New Guinea, Tasmania, New Zealand and Islands of the Pacific.

Altitudinal Distribution.—Organisms show different types of physical distribution as well as topographical. These may be *terrestrial*, *aquatic*, or *aerial*.

a. Aquatic Fauna.—In sea, ocean, lake, pond and river there is a great variation in conditions. The ocean is said to have been the first home of living things. Many of the lower forms are restricted to it. All Echinodermata still live in it; almost all of the Porifera and most of the Coelenterates and Annelids while terrestrial and aquatic types, appear among the Molluscs, Arthropods and Vertebrates. Some former terrestrial forms, a few Insects, Birds, and Mammals (Cetacea and Sirenia) have returned to the water.

1. Pelagic animals are surface forms which live at a distance from the land. This may be called the Pelagic Zone. They are mostly Protozoa and Coelenterates with some Molluscs, Arthropods, Tunicates and Fishes. Many others have eggs or larvae that are pelagic. The food of pelagic forms consists largely of microscopic Algae.

2. The Neritic Zone extends from high-water mark to a depth of 500 fathoms (about 3000 feet). Some of these forms are littoral, occur along the shores where there are great extremes of temperature, and sometimes at low tide the animals are stranded out of water. Some are bottom living forms (*Benthos*) and some of these remain fixed to some object and others crawl over the bottom. Most aquatic animals live in this zone.

3. Abysmal Zone. Here are animals living in waters below the 500-fathom mark. These waters are eternally dark, unagitated, very cold and without plant life. This is the graveyard of the skeletons and shells of animals of the upper waters. Almost all the phyla have representatives among these populations of the great deep. The pressure is enormous—at 2500 fathoms being $2\frac{1}{2}$ tons to the square inch. The abysmal forms are carnivorous and many are blind and many are phosphorescent. Fresh waters also contain pelagic, swimming and bottom living forms.

b. Terrestrial Fauna.—The animals that have been able to migrate from water to land are, for the most part, certain Arthropods and Vertebrates. Among the Arthropods, the greatest terrestrial group is the class Insecta. Flatworms, Roundworms, Annelids and Molluscs also occur on land.

c. Aerial Fauna.—But few kinds of animals have been able to achieve the ability to fly—they are for the most part Insects and Birds, a few Mammals (bats) and some extinct Reptiles (pterodactyls). It has been suggested that the first animals were pelagic drifters, then came swimming forms, those that explored waters horizontally and vertically. From these were derived the abysmal forms and also the fresh-water forms. From the latter arose the terrestrial and aerial types. During this period, however, many reverse migrations (such as Cetacea) took place and other forms such as marine crabs, moved directly to the land.

Palaeontology.—Palaeontology is that portion of Biological science that deals with organisms which once lived on the earth and are now found buried in it as *fossils.* A fossil is the rock-like remains of a former living organism.

The word literally means something that is "dug up." Fossils are usually petrified teeth, bones, shells or wood. Soft parts, such as muscles and viscera, usually disintegrated too soon to become permanently recorded as fossils. Not all localities are favorable for such preservation. Pressure, elevation foldings and erosion destroy fossils. Often they are discovered accidentally when a cut is made through a hill for a railroad. Erosion may uncover them. At rare intervals extensive deposits of fossils are discovered. It is after all, remarkable that enough material has been recovered to make posible the science of Palaeontology, when one considers the very many conditions operating against the preservation and discovery of such specimens.

Fossils were not unknown to the ancients. Aristotle thought they were examples of spontaneous generation taking place in the depths of the earth, and that such forms never had a chance to live on the surface. When hippopotamus bones were found in Sicily, Empedocles (450 B.C.) thought they indicated a great battle in ancient times between giants and Gods. Xenophanes of Colophon (500 B.C.) found fossil fish in rocks near ancient Syracuse and thought they had been caught in the rocks when these were under water. Nearly two thousand years later Leonardo da Vinci, a man of unusual common sense or rather uncommon sense, urged that fossils were the remains of former living animals. In fact, Steno, professor of anatomy at Padua in 1669, compared the teeth of living sharks with similar fossil structures and asserted that they were identical. During the 18th century it was commonly believed that fossils were remains of animals that died in the great flood of Noah's time. For example, one specimen appeared to be the fossil skeleton of a child. This afterwards proved to be a large salamander.

It is said that Werner (1750–1817) first suggested that the relative age of different rock strata could be identified by their fossils. This method is employed to-day and is known as the "*Fossil Index.*" Werner also noted that fossils more nearly like existing living species, occurred in more recent strata. Cuvier, the distinguished comparative

anatomist of France (Fig. 327) studied fossils of Vertebrates unearthed near Paris. He asserted that they ought to be listed with living animals. He would not acknowledge that any living forms were descended from such ancestors and in attempting to account for their distribution claimed that there had been eight great successive catastrophes like the flood in Noah's time. Lamarck studied Invertebrates, showing, for example, that some fossil molluscs were similar to living forms and that some had long ago become extinct. This had a distant bearing on the theory of evolution which he developed. William Smith (1769–1839), an English surveyor, suggested that there had been a regular succession of layers of rock or strata, because certain similar fossils always occurred in certain strata, and other types of fossils would be found in deeper strata.

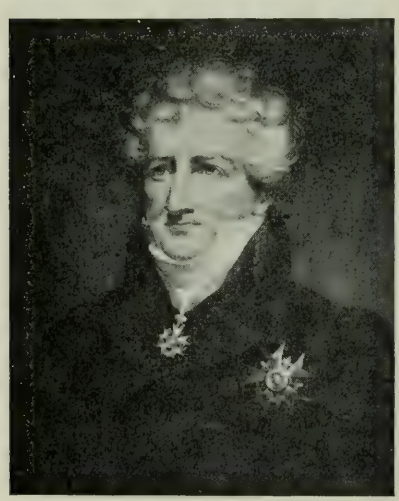

Fig. 327.—Georges Cuvier, 1769–1832. Comparative anatomist.

In 1830, Charles Lyell (Fig. 328), an English geologist, published an epoch-making book in which he presented a new (and what is still held to be true) explanation of the history of the earth. He held that forces present to-day operated likewise in the past and that these forces not only brought about the changes in the earth's crust in the past but are doing so to-day; that it is a continuous process. Streams cut down continents, and transport material to new places. Changes in temperature, wind, waves, volcanoes and glaciers have long been at work. Animals died all along the line of time; they were later buried. This process took thousands upon thousands of years and in this period there was a succession of animal forms.

It is impossible to state the age of the earth with any degree of accuracy. It is believed that the earth was born and arose from matter thrown off from the sun. Atmosphere and water appeared, oceans and land. Long afterwards living substance was formed and unicellular forms appeared. This was in the (1) Archeozoic Era represented by the strata of the ancient Keewatin and Laurentian periods. Then after the ancient Laurentian period, came the (2) Proterozoic Era, of long duration. During the successively appearing periods primitive Invertebrates appeared and flourished. There were two ice ages during this era. Then came the (3) Paleozoic Era. In the earliest or Cambrian periods of this Era, higher Invertebrates, shelled forms, dominated. In the next, or Ordovician period, appear the first-known fresh-water fishes. In the next later or Silurian period, the first-known land Flora appeared. In the Devonian, marine fishes. Later in the Mississipian great marine sharks flourished and were the dominant animals of the sea. Higher up (later) in the Pennsylvanian period insects appeared and giant Pteridophytes (Fig. 329). These latter formed the coal beds. In the next or Permian period, reptiles arrived. (4) The Mesozoic Era succeeded the Paleozoic. This Era was distinctly an age of Reptiles. It is subdivided into the lower Triassic, in which giant reptiles called Dinosaurs flourished, and where the ancestors of Mammals also appeared for the first time. Next the Jurassic when flying reptiles, Pterodactyls, and feathered birds appeared. In a later period, the Comanchian, flowering

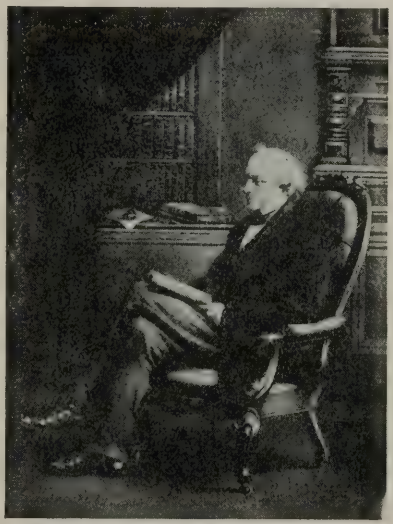

Fig. 328.—Charles Lyell—geologist. 1797–1875.

plants and insects, correlated with them, appeared; then in the still later Cretaceous, came primitive Mammals. The Mesozoic was followed by the (5) Cenozoic. In the early Cenozoic, higher Mammals and Primates are found. In late Cenozoic (Pliocene and Miocene) the higher Apes and Man emerged. The Pleistocene was the time of the last great ice flood or Glacial period. Finally came the Psychozoic, which began some 30,000 years ago and is the Age of Man.

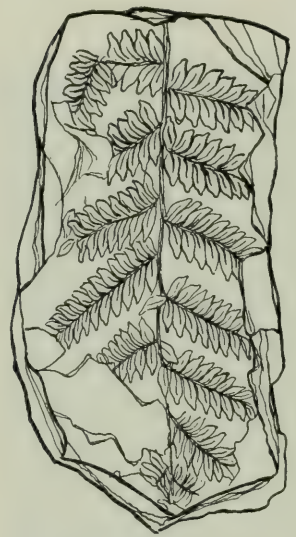

FIG. 329.—FOSSIL FERN FROM CARBONACEOUS SHALE.

It is evident that Invertebrates appeared long before Vertebrates, Fishes before Amphibia, Ferns before Flowering Plants, Reptiles before Birds and Mammals. The lower strata contain simpler forms, the more superficial (later or younger) strata show more complex forms. Any locality on the earth's surface may have once been the floor of the sea. Corals are now found in fossil beds, hundreds of miles from the ocean. Tropical forms are found in localities that now have severe winters. North and South America were separated from Middle Eocene time to late Miocene. There are evidences of great migrations of animals in response to great climatic changes. Either the migration or the great environmental changes may have produced new species. Lull says: "The animals followed three great evolutionary lines, culminating in the Molluscs, the Arthropods and the Vertebrates; of these the Cephalopods represent the final goal of molluscan evolution, the Insects of arthropod evolution and the Mammals of vertebrate evolution."

The *Cephalopods* are divided into such naked-aggressive, active forms as squids and such forms as the armored (shell) and sluggish Nautilus. The history of the latter types

can be studied by the Palaeontologist on account of the preservation of the shell in fossil form. A four-gilled type, tetra-branchiate, had a more resistant shell than the more modern two-gilled forms. The first type had long, tapering, cone-like shells. They were common throughout the Paleozoic, but began to wane late in that era though some were still present in the early Mesozoic. In the later descendants, the shell was wound in a spiral. A few of the nautilus forms still exist to-day, although this type is approaching extinction.

The insects are supposed to have been derived from a primitive arthropod type called *trilobite*. They had amphibious habits and had a number of similar segments, and lived in the early Paleozoic era. From this type also originated Crustacea and some of the Arachnida. The ancient insects were carnivorous and aquatic. During the late Permian and early Triassic, insects were rare. Conditions had changed from a moist, warm climate to one cold and dry. Plant life was changing. Other types of animals responded to the change. Insects became more numerous in the lower Jurassic. The first Lepidoptera appeared in the middle Jurassic, and the first Hymenoptera in the upper Jurassic. These insects were plant eaters. In the Cretaceous appeared a wonderful development of Flowering Plants, and Lepidoptera and Hymenoptera associated with them. This proved to be of mutual advantage to both flower-visiting insects and the flowering plants and had a great deal to do with the rapid extension of these Spermatophytes. In the Tertiary, all the higher types of insects were well-established, social insects and parasitic forms as well. Lull says that the primary cause for the origin of insects from Trilobites was the great development of land flora in the Silurian and Devonian age of the Paleozoic (Carboniferous) era. The profound change in climate in the Permian period not only almost destroyed the Pteridophyte Flora, but introduced metamorphosis in insects by which they could survive inclemency of climate. The appearance of flowers in the Cretaceous is very important.

The emergence of *Fishes* from invertebrate types is

involved in so much debate that it is advisable to omit discussion of it here and to refer the student to such treatises as Lull's "Organic Evolution," and Wilder's "History of the Human Body." The Carboniferous division of the late Paleozoic comprises the Mississipian, Pennsylvanian and Permian Periods. During the first part of this period the climate was warm and moist. It was the great Coal age during which those great Pteridophytes thrived. They were spore-bearing, rapid-growing and soft-wooded. These in turn were almost destroyed by the icy Permian climate. During the Mississipian period sharks were the dominant fishes of the oceans. The first amphibian bones came from the lower carboniferous. Late in this period dry seasons appeared which were favorable to amphibian life on the land. These animals probably went back to the water for breeding. The largest of these were the Stegocephalians which were salamander-like forms with bony dermal plates on the dorsal surface of the body. They were about three feet in length.

The *Reptiles* probably originated from stegocephalian-like forms in the Carboniferous. The Permian furnished specimens of five out of the fifteen orders of Reptiles recognized by some authorities. From a short-legged, crawling, generalized type there developed arboreal and burrowing forms. This is an illustration of adaptive radiation. It appears in the development of insects and was first clearly pointed out in the case of mammals by Osborn. The Mesozoic has been called the Age of Reptiles, and America was the scene of their greatest developmental activity. Some were like modern crocodiles and turtles, aquatic forms or dwellers in swamps. There were great sea reptiles (Fig. 330) in an ocean which had no whales. There were flying reptiles, or Pterodactyls in the air which had no birds. The land forms were called *Dinosaurs*. They ranged in size from about that of a cat to forms vastly larger than the elephant. Their bodies were short and stocky, their legs were long. Unlike modern quadruped reptiles, they walked or ran on their hind legs, the tail acting as a balancing organ as in the Kangaroo. The Dinosaurs were the dominant land Ver-

tebrates for nine million years. The early forms were much like modern lizards. But from this type many diverse forms developed; some of great size, some carnivorous, some herbivorous, some protected with a bony armor, some quadrupeds, and some bipeds.

Tyrannosaurus (Fig. 331).—The "Tyrant Saurian" (Osborn) represents the extreme development of carnivorous Dinosaurs. It was forty-seven feet long. The head was over four feet long, its great jaws had teeth from three to six inches long, and the toes were armed with sharp curved claws six or eight inches in length. The head was twenty feet above ground when the animal stood up. The bend of

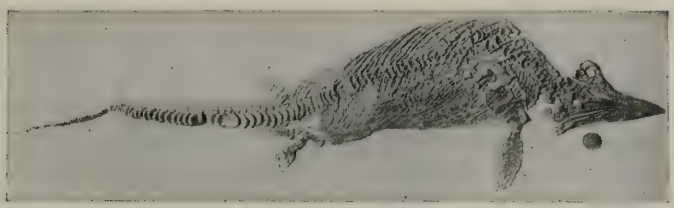

FIG. 330.—FISH-LIZARD OR ICHTHYOSAUR.

In Museum of Natural History, College of the City of New York. (Photo by Stratford.)

the knee was six feet above the ground. Its forelimbs were small and it moved about on its hind limbs, and was *digitigrade*, like an ostrich. Its movements were slow and ponderous, hard to start, and difficult to stop. Its brain was small. Its actions were probably instinctive. It is supposed to be the largest carnivorous animal that ever lived.

Brontosaurus, called the "Thunder Saurian" by Prof. Marsh, was a great amphibious Dinosaur. Its skeleton was discovered near Medicine Bow, Wyoming, in 1898. It took two years to remove the fossil remains. It was sixty-six feet, eight inches long, and probably weighed thirty-eight tons. It was placed on exhibition at the American Museum of Natural History in New York, in 1905. It had a long thick tail, a long neck, a short body and solid, heavy, pillar-like limbs. Its head was comparatively small. It probably ate soft plants and lived in shallow waters, rich in

plant life, crawling out upon the land to lay eggs. Matthew appropriately names it the " Leviathan of the Shallows." *Diplodocus* was not so bulky as Brontosaurus. A skeleton in the Carnegie Museum of Pittsburg is eighty-seven feet long.

The duck-billed Dinosaur, *Trachodon*, was over sixteen feet high when standing. It was herbivorous and the mouth was expanded into a broad duck-bill covered with a horny sheath. The teeth totaled over 2000 in both jaws. The American Museum of Natural History in New York was

FIG. 331.—TYRANNOSAURUS REX.

Compare with human skeleton at left. This was the largest carnivore that ever lived. (American Museum of Natural History.)

fortunate in obtaining a rare specimen in which the skin has been preserved. The animal had apparently died a natural death and the soft parts, instead of decaying, were preserved for a time by desiccation in the hot sun, until petrifaction preserved it as a fossil mummy.

Triceratops was a great horned Dinosaur nearly as large as the elephant. The skull found had extending from just behind the eyes, a pair of long, pointed horns nearly three feet in length. In addition, it had a single short front horn rising from the nasal bones. Extending from the back and sides of the skull is a great bony flange or frill. In some cases, the skull was seven or eight feet long and three feet

wide. In general appearance it suggests a union of the modern rhinoceros, elephant, and hippopotamus.

During the Upper Cretaceous period and near the close of the age of Reptiles, the climate of northern North America was similar to that prevailing now in Southern California. Plant fossils indicate the existence of fig trees, palms, and the horsetail. Fresh-water clams lived in the rivers. With the close of the Mesozoic, the dominant position long maintained by the Dinosaur Reptiles was lost. Not one trace of them appears in the Tertiary. As stated they had thrived for nine million years. It is a great life cycle with its period of humble birth, its morning of youth, the noontime of its glory, and its evening of death. Lull ascribes extinction to great elevation of land areas, the draining of great inland seas, and the restriction of old haunts.

Huxley has called *Birds*, " glorified reptiles " a simile justified by the results of embryological and anatomical comparisons. The origin of Birds from Reptiles is buried in obscurity. *Archaeopteryx* is the earliest known bird, found in the upper Jurassic and contemporary with early Dinosaurs. A description has already been given. It is not amiss here to recall the teeth in both jaws, the three-clawed fingers of the hand, and the long tail with a row of feathers on each side. *Hesperonis* was discovered in the Cretaceous of Kansas. It was about four and one-half feet long. It could not fly, but had long powerful hind limbs and was probably an excellent diver and swimmer. It possessed teeth. *Ichthyornis* was much like our modern gulls and possessed the power of flight. It was smaller but had teeth. It was in most respects like modern birds. The birds of the next era, Cenozoic, were even more like modern birds.

Mammals are regarded as having arisen from small reptiles called *Cynodonts* found in the Triassic period of the Mesozoic. The teeth of these Reptiles were divided into incisors, canines and molars, as is characteristic of the Mammals. It is even claimed that the early mammals first appeared in South Africa. The increasing dryness of the climate and formation of dry land acted as stimuli to the development of a speedy form.

The appearance of glacial conditions made necessary some method of retaining body heat and maintaining a constant body temperature. They were held in check all during the age of Reptiles. Their greatest enemies were fierce, gigantic, carnivorous Dinosaurs. From these enemies, the small and apparently defenseless mammals managed to survive sufficiently to keep the Mammalian line alive during all those years until after the fall of the Dinosaurs, when the Mammals gloriously emerged in the early Cenozoic.

It is impossible in this brief review to study the palaeontological history of all forms of Mammals. The history of the Horse is one of the most complete studies in this field. The wild horses found on our western plains were not immediately indigenous to America. They were *feral* (escaped from domestication) descendants of domestic horses brought to this country from Europe by early expeditions, such as those of the Spanish. In many of these, the human members perished, but the horses roamed the wilderness, left offspring and so spread. A more ancient history of the horse has been painstakingly investigated. It has been traced back by a series of stages to the lower Eocene, early in the Cenozoic Era, 3,000,000 years ago. The scene of great activity in its development was in America. (1) *Eohippus* (Fig. 332) found in the lower Eocene was about a foot high. The forefoot had four toes and a splint bone (1st) on the inner side, which indicates that it had a five-toed ancestry. The hind foot had three toes. There is no sign of the first but a splint bone represents the fifth on the outer side.

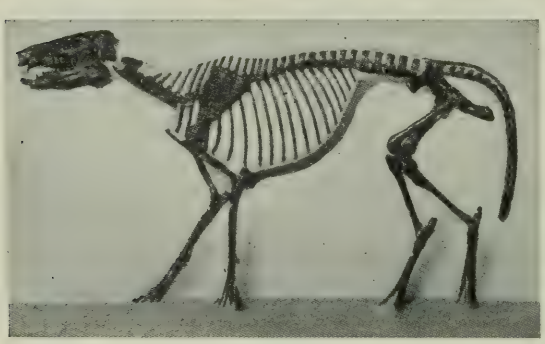

FIG. 332.—EOHIPPUS.

A four-toed horse from the lower Eocene. (Amer. Mus. Nat. Hist.)

This indicates a tendency toward the loss of the first and fifth toes. The teeth had long roots and short crowns. The upper surface had several cusps. The skull was small and the lower jaw short. The face was short. (2) Mesohippus, found in the next era, the Oligocene, was about eighteen inches tall. It has only three toes on the hind feet but the fifth toe of the front feet was a splint bone. The middle toe (third) on each foot was longer than the others. It was similar in appearance to that of Eohippus, but the cusps on the teeth were united into ridges. It probably fed on green juicy grass or leaves, as Eohippus had done. (3) *Merychippus* was found in the Miocene and was about three feet high. All four feet had only three toes as a rule, but the third (middle) was distinctly longer and the second and fourth well above the ground. The upper surface of the molar teeth had worn down to a flat grinding surface in which enamel ridges occurred. The lower jaw was accordingly heavier. The eye orbit was placed further back, showing an increase of the length of the facial part of the skull. Jaws and teeth indicate its food to have been dried grass growing on dry plains to which its feet were more adapted. (4) *Pliochippus*, found in the Pliocene, had two lateral toes which were mere splint bones. It was functionally a one-toed horse and the teeth had grinding surfaces. (5) *Equus*, the fossil horse of the Pleistocene, was very much like the modern horses. It was five feet or more in height. There was but one toe, the third, on each foot. The animal stood on its toes. The second and fourth toes were mere vestiges. The upper surface of the teeth is ground flat and continued to grow as it wore away. Lateral ridges of enamel alternated between spaces of dentine and cement which soon wore away and left sharp enamel ridges very useful in cutting up the food. The eye was set well back and the face was long. (Fig. 333.)

When Eohippus lived in America the climate was humid and this little horse-like animal lived on marshy ground. Later the climate changed. The air became dry, the streams dried up, and hard plains were formed. One-toed forms were better suited to these conditions. From juicy

green stems and plants the vegetation changed to dried grass, and the change in teeth and form of skull were adapted to this.

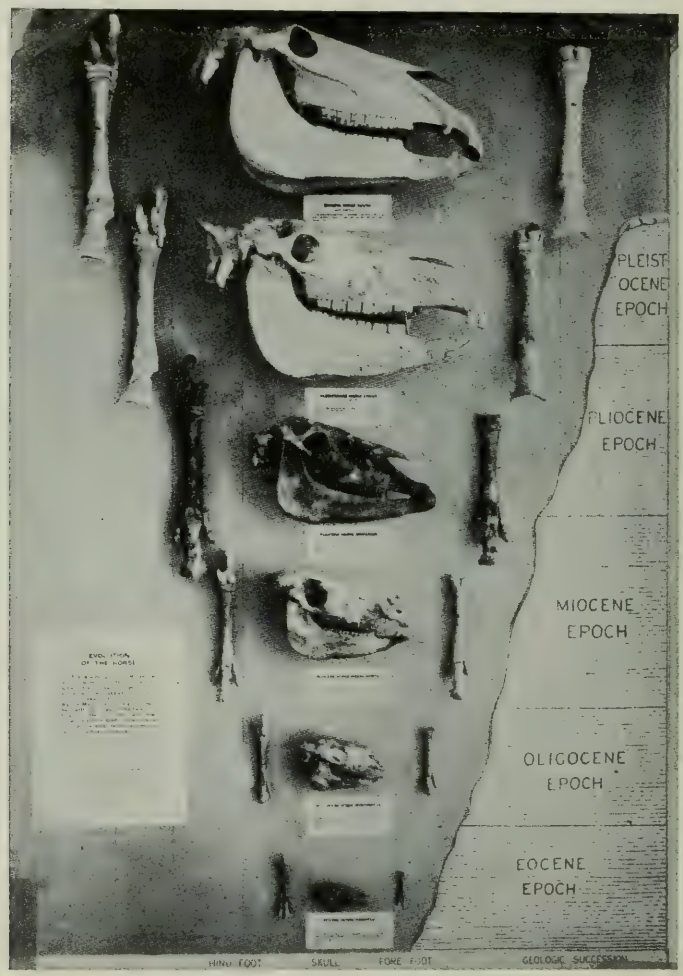

FIG. 333.—EVOLUTION OF THE HORSE.

Left, evolution of hind foot; middle, head; right, fore foot. (Matthew, Amer. Mus. Nat. Hist.)

The history of the Camel shows that its ancestor, *Protylopus*, was about the size of a rabbit and lived in North

America and the four feet had four distinct, useful toes. The first was not represented. The hind feet had two toes. This animal occurs in the late Eocene. From it sprang three lines of descendants. Two of these have disappeared. The third line lived in North America until late Plicoene or Pleistocene, when it migrated to South America, Asia and Africa. The llama and alpaca are domesticated representatives of the South American form. In Asia and Africa

FIG. 334.—RESTORATION OF ELEPHAS PRIMIGENIUS, THE MAMMOTH.
(From painting by Charles R. Knight, Amer. Mus. Nat. Hist., after Osborn.)

this living line is represented by the dromedary, or one-humped camel, and also the two-humped form. These have been domesticated for thousands of years. There are no other wild forms.

The evolution of the Elephant can be clearly traced from the late Eocene onwards. The fossil remains of a form named *Moeritherium* were found near Cairo, Egypt. This animal was probably about three and one-half feet high. The Mastodons lived in the Pliocene and Pleistocene and were not in the same immediate line of ancestry as modern elephants. They ranged from Europe across Asia to

Alaska and south through the United States. They fed on twigs of evergreen trees. Remains have been found in swamps in several of the states, i.e., New York, Indiana, Ohio. *Elephas primigenius* (Fig. 334), the hairy or woolly Mammoth, closely related to the living Asiatic elephant, was provided with long black hair and thick brown wool enabling it to survive Arctic cold. It could withstand the rigors of an ice age. Frozen specimens have been taken from the ice in Siberia. One was discovered frozen in clear ice in 1799, and another in 1901. These animals were known to prehistoric man. Primitive artists made drawings of the Mammoth on the walls of caves. Tusks of extinct Mammoths make up one-half of the ivory supplied to the trade. Several thousand of these have been found. Mammoths flourished in the Pliocene and Pleistocene. They have been extinct for thousands of years. The only living representatives of the elephant group are the Indian and African species. *Elephas indicus* lives in certain Asiatic forests, such as those of India, Ceylon, and Burma. The African elephant, *Elephas africanus*, is larger, has enormous ears and longer tusks. Its ivory is more highly prized than that of the Indian elephant.

The Miocene was a period of great mammalian development. Climatic and earth changes took place in the Pliocene. Old land bridges disappeared and new ones were formed. Migrations of animals consequently took place so far as possible. Of all the forms, this was more possible in the case of Birds and Mammals. Man is thought to have arisen in this age. With the Pleistocene, during which the rise or elevation of the continents continued, the age of ice began. There were long periods of bitter cold alternating with short periods of warmer climate. Many kinds of animals were destroyed. Man was able to withstand such rigors and, during these long terrible ages, managed to keep the torch of human life aflame until the ice gradually melted further and further north and the Psychozoic Age appeared. Then the Age of Reason and Intelligence and what is known as Human History finally began.

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CHAPTER XXVII

HEREDITY

The fertilized egg develops into an adult organism. It is common knowledge that the offspring is like the parent. A certain strain of wheat is like its parent in hardness, gluten quality, early ripening, and resistance to rust. The offspring of domestic cats are domestic cats. We know beforehand that they will be animals, not plants; Chordates, not Molluscs; Mammals, not Amphibians; Carnivora, not Primates; Felidae, not Canidae. They will be *domestic* cats, not tigers. This is so universal as to seem not worthy of mention. But, in addition, the kitten will grow up into a cat possessing in detailed respects characteristics of its particular parents and possibly not represented by all cats. The study of these resemblances produced in descent constitutes the science of Heredity or Genetics—the science of *Generation.* All generations come from preceding generations. In biological history there is organic continuity. Genetics of itself is specific; it is not concerned with the broad questions of generation of groups or kinds of organisms. It studies the question of the detailed inheritances of offspring. Its results, however, throw important light on the broader questions of evolution, the generation of races. The question of evolution needs the information given by Genetics.

The general result of asexual reproduction is the production of replicas of the parent. In spite of the fact that these uniparental offspring may be introduced into conditions varying somewhat from those surrounding their parents, they remain apparently the same, generation after generation. Amoeba divides into two daughter cells. Each daughter cell is given part of the protoplasm of the parent

and the daughter protoplasms are alike. It is easy to understand why offspring produced by asexual reproduction are just like their parents, and so such cases present few genetic problems. But this is not the case in *sexual reproduction.* Offspring cannot be just like their parents unless the type of reproduction has from the beginning been one of constant inbreeding between brothers and sisters of the same generation. It can safely be stated that no two individuals developing from separate fertilized eggs are ever identical. Each is the only one of its kind that ever existed. It is *sui generis.*

In sexual reproduction the offspring does not develop from the parents' heart or muscles or liver or any of the other organs of metabolism or adjustment. It develops from a fertilized egg which is the result of the union of an egg cell and a sperm cell.

The animal, chordate, mammalian, carnivore, cat-like characteristics of the kitten referred to above must have been present in some form in the spermatazoan and egg, for enough evidence has been produced to show that they are somehow resident, in part, in the sperm as well as the egg. Not only are the general characteristics, above referred to, so represented, but even the peculiar things which mark this animal as a unique individual. There is no other bridge between generations but germ cells. It is evident, therefore, that not only should an exact study be made as to just what and how characteristics are inherited by children from parents, but also serious investigations be made of the nature of the egg and sperm in heredity.

An individual is the sum of all its characteristics. Of course the sum of all the characteristics would not be the individual. But we distinguish one individual from another by such characters.

Variation.—In spite of the resemblance between parent and offspring, there are also differences. These demand investigation. The assertion has been made that differences or variations between organisms are universal. In fact, as Walter has said, it is " the unvarying thing in nature," i.e., when one is dealing with the products of sexual

reproduction. What are the evidences of this assertion? Bateson, in 1894, collected a great mass of instances of these in his " Materials for the Study of Evolution." The modern custom of recording fingerprints by the police is an illustration of one form of the universal variation in human beings. Walter lists ten types of variations. (Fig. 335.) For example, men vary as to height; vary as to immunity from disease; and in their artistic sense. Some variations

FIG. 335.—VARIATION IN COLOR, SHAPE, SIZE, AND SURFACE OF FRUIT OF SUMMER SQUASH.

All may be descendants of a single individual. (From Sinnott's Botany.)

are useful, some have no apparent use; some are normal, some abnormal, like a four-legged chicken. A continuous or gradual variation is found in the height of men. Other variations are discontinuous, or abrupt. Earthworms differ as to the number of complete segments not in fractions of an inch. Some variations are inherited by offspring, while some are not.

Charles Darwin simply described isolated examples of variation. His cousin, Francis Galton, studied these variations more carefully employing mathematics in an attempt

to arrive at general conclusions. Karl Pearson more recently applied the method of mathematical analysis and so *Biometry* has become a distinct field of biological research. Only a brief reference to Biometry can be made here. For example, the number of segments in 154 earthworms was counted. It was found that the arithmetical average of the number of segments was 144.83. But no earthworm has a fraction of a segment. Moreover, this is merely one fact, it gives no picture of the variation in segment number of earthworms as a whole. A better way to do this is to establish successive classes of segment numbers and determine the number of worms in each class. As 92 worms had between 142 and 152 segments, we know that more worms have between 142 and 152 segments than any other segment number. This is known as the biological average or mode of this group of worms, for it is a number which actually exists in nature. If a thousand worms had been studied smaller range of classes could have been used. Examination of the results shows at once a considerable degree of variation. There are deviations from the mode. Some are below the mode or minus deviations and other are above the mode or plus. It will be observed that the sum of the minus deviations is about equal to the sum of the plus deviations. When the results are plotted in the form of a curve the abscissae mark the classes of number of segments and the ordinates mark the number of worms in each class. A line drawn through the points of intersection shows the curve of variation.

This mode is 142–152 segments and it is this class which contains the greatest number of earthworms. Now it is possible to represent graphically the variation in number in a large number of earthworms of the same species gathered in some other distant locality. If the two differ markedly it would present a problem for careful investigation as to effects of environmental conditions on the number of segments of this species of earthworm. If the external conditions are stable, a small degree of variation would indicate complete adjustment of the species to these conditions, while if there is a great degree of variation, this would tend to

indicate incomplete adjustment. The form may have newly invaded this territory and had not as yet " settled down."

To measure the degree of variation the biometricians have adopted the standard deviation which is represented by the Greek letter " s " or " σ " and the value of " σ " is obtained from the following formula: $\sigma = \sqrt{\frac{\Sigma(x^2 f)}{n}}$ in which, Σ = the sum of the classes, x is the deviation of each class from the arithmetical mean; f = the number of individuals in each class; n = the total number of specimens. The standard deviation has no significance in itself, but is only of value in comparing standard deviations of other groups for the purpose of comparing variability in different lots of individuals. Jennings investigated the body width of apparently similar Paramoecia found in a certain culture. When he plotted the results a bimodal curve appeared.

It was later found out that the general population consisted of two kinds of closely related forms that would not have been suspected had the matter not been given this mathematical treatment. It is not easy to establish classes when variations in color are being investigated. In this case, classes are arbitrarily established. When this is done even such graduated variations can be treated biometrically. The bearing of variation on problems of Evolution is discussed later.

Biometry has also been used in the investigation of heredity. Galton was a pioneer in this field. His results appeared in a book entitled " Hereditary Genius," published in 1869. He studied statistically certain easily measurable human characters in parents and offspring. He obtained the height of 204 English parents of graduated statures and their 928 mature children. The average height of females is less than that of males by 8 per cent, so Galton multiplied each female height by 1.08 to bring female height to the same standard as male height. He then added the height of the father to the corrected height of mother and divided the result by two. This gave him

one number for the height of the two parents. The results in inches were as follows:

Parental height...	64.5	65.5	66.5	67.5	68.5	69.5	70.5	71.5	72.5
Height of children.	65.8	66.7	67.2	67.6	68.3	68.9	69.5	69.9	72.2

A study of these results shows that the mean height of the parents is 68.5; of children 68.3. One also notes that the children of the shortest are taller than their parents and also that the children of the tall parents are shorter than their parents. This indicates a tendency toward the average height, and is known as *Galton's Law of Filial Regression* which is stated thus: Average parents produce average offspring: tall parents produce tall children, short parents produce short children, but the children are not as tall or as short as their parents, that is, there is a tendency toward the average condition; the children inherit the parental characteristics in a less diverse degree. Galton would have this law apply to inheritance of all sorts of characters, mental as well as physical. He made a more definite assertion derived from mathematical consideration of the results, namely that children show only two-thirds of the parental deviation from the racial average. By his statistical methods he arrived at another general conclusion known as the *Law of Ancestral Inheritance.* According to this he asserted that the two parents contributed one-half of the total inheritance of the child; the four grandparents, one-fourth; the eight great-grandparents, one-eighth, etc. These studies gave general information of a sort, but the plan of attack was not appropiate for the study of individual cases.

To ascertain exactly what is inherited and to what degree, one must study in detail individual cases of inheritance, and, not in any one generation, but in successive generations, and, moreover, it should be attacked experimentally. For example, both parents or a group of parents possess a certain character. Interbreed them. Do the offspring possess that character? Interbreed these. Do *their* offspring exhibit the character? And so on. Or one variation in a character is possessed by one parent; another variation by another parent. On breeding these, which

kind of variation is possessed by the offspring? Continue inbreeding. Is there any general agreement in the results? Will such experiments reveal any general laws or principles of Heredity so that application of them at any time will work out according to law? Some such method of attack occurred to a number of investigators who found that mass statistics gave limited results. The three pioneers were DeVries of Holland, von Tschermak of Austria, and Correns of Germany in the year 1900. These men made the remarkable discovery that this method had been employed nearly forty years before by an earlier pioneer, Gregor Mendel, a priest living at Brünn, Austria. Just after the rediscovery, in 1900, of Mendel's paper which had been published in an obscure journal, other workers at once appeared, such as Bateson in England and Davenport and Castle in America. Mendel had studied science at the University of Vienna. About 1857 he began an experimental inquiry into heredity. He worked painstakingly and successfully for eight years. As Castle says " his keen analytical mind enabled him to plan and execute the most original and fruitful investigations on heredity ever completed." Father Mendel published his epoch-making results in the journal of the local natural history society. He sent Nägeli an account of his work but Nägeli was more interested in other things just then and paid no real attention to them. Charles Darwin had published the epoch-making " Origin of Species " but a few years before. It is interesting to speculate as to what would have resulted for science had Darwin known Mendel's work. It should be recalled that Mendel was working at about the time that Galton's studies in heredity were receiving attention.

Mendel worked with varieties of garden peas. There is little variation within each variety because they are self-fertilized. Pollen from the stamens produces sperm cells which fertilize the egg cells in the ovaries of the same flower. Mendel noted that each variety had distinctive characters. One variety was tall, another was dwarf; one variety had smooth coated seeds, another had wrinkled seeds; one had green colored seeds, another had yellow seeds. Moreover, there was practically no graduation between green and

yellow, between smooth and wrinkled, between tall and dwarf. Mendel examined his population of peas carefully and chose seven pairs of distinctly contrasting characters to work with. He determined to cross peas possessing contrasting or alternative characters. To cross or hybridize them he had to proceed as follows: For example, to cross a *tall* with a *dwarf* pea, it was necessary to remove all the stamens from *tall* plant flowers and place on their stigmas pollen from *dwarf* plant flowers and vice versa. He found that it made no difference which was taken as female or male, so far as inheritance was concerned. At first he worked with one character alone in mind. To understand his work a simple typical experiment is described. He crossed tall with dwarf peas. The resulting seed from this parental generation were all carefully saved and planted the next Spring. They developed into *tall* pea plants exclusively. If there was any dwarfness about them it was hidden. So at once Mendel called tallness *dominant* and dwarfness *recessive*. During the second summer he crossed these *tall hybrid* plants, carefully collecting the seeds as before. He planted them during the third summer, and *dwarf* plants reappeared. He counted the two lots. There were about three times as many talls as dwarfs. The actual numbers were 787 talls and 277 dwarfs. To designate these groups more definitely, the larger group of talls will be called 3T and the smaller group of dwarfs 1D. On intercrossing the 1D's, the resulting plants during the fourth summer were all dwarfs. He crossed these again, and the next summer they were all dwarf again and the result continued to be the same. This showed that the first 1D's to reappear were pure recessives again like their grandparents.

But what about the 3T's? Mendel inbred them. In the third summer their population was in the proportion of 3 talls to 1 dwarf again. The 3T's could not have been all pure talls or pure dominants because on inbreeding they produced some recessives. But nevertheless, they might have contained some pure dominants like the original grandparent, and also some hybrids like the parents. This proved to be the case because Mendel was able to show that the 3T offspring in the second filial generation consisted of

one-third pure dominants and two-thirds hybrids or impure dominants. But of the whole population of the second filial generation this meant that $\frac{1}{4}$ were pure dominant T; $\frac{1}{2}$T(D) or impure dominant and $\frac{1}{4}$D or pure recessive. This can be proved by the following experiments. Cross a 3T plant with a known pure Recessive D. If all the progeny are tall, then the tall parent must have been *pure* tall for the offspring are just like the first generation resulting from interbreeding pure talls and dwarfs. On the other hand, the results might be 50 per cent tall and 50 per cent pure dwarf. In this case the tall parent must have been impure. This is known as back crossing and is made clearer presently.

Similar proportions obtained when Mendel interbred the other pairs of characters. On crossing yellow-seeded peas with green-seeded he obtained, in the second filial generation, 6022 yellow peas to 2001 green peas, and in another experiment, 5474 round seeds to 1850 wrinkled seeds or about a proportion of 3 to 1 in each case as before when hybrids were crossed.

Mendel went further than this and tried to conceive of an explanation. He thought that the matter had to do with the difference between the germ cells and the cells of the organism resulting from their union, that is, gametes and zygote. He was endowed with an analytical mind. An explanation occurred to him. Suppose the germ cells alone were pure with respect to one or the other of contrasting characters? Why not cross pure dominant with pure dominant? If (D) (meaning dominant) is true of both male and female gametes then all offspring are Dominant. If male (R) mates with female (R) then pure recessives result. But if some gametes are (D) and some (R) then the result is a hybrid, impure dominant. Possibly the zygote is D(R). This at once suggests that the zygote is not always pure with regard to alternative characters although its gametes may be. To test this hypothesis cross impure dominant with impure dominant. If the hypothesis is correct then it might be expressed as follows: in which case 50 per cent of the male gametes are D and 50 per cent are R and the same is true of female gametes.

50% 50%

Male ♂ gametes D R —From Impure Dominant Male Zygote

Female ♀ gametes D R —From Impure Dominant Female Zygote

DD——DR

DR——RR

Zygotes 1DD——2DR——1RR or 25% DD+50%DR+25% RR.

The result is just what was found to be true when tried by experiment.

Germ cells are pure with respect to any one of a pair of contrasting characters, but the zygote may carry *both*, although one may not appear in the zygote which would form germ cells bearing that character as well as germ cells bearing the other character.

Inheritance is affected by interbreeding pure dominant with impure dominant and it makes no difference which is male or female. The important thing is what types of gametes unite. It may be represented thus:

Male gametes D D —Pure Dominant

Female gametes D R —Impure Dominant

DD——DD

DR——DR or 2DD : 2DR. But this actually did appear.

Now if *impure* dominant is interbred with pure recessive. It would be expressed

Male gametes D——R —Impure Dominant

Female gametes R——R —Pure Recessive

DR——RR

DR——RR or 2 DR : 2 RR, and this again worked out.

It would appear as though zygote cells have double factors for characters and that germ cells have single factors for characters.

Since Mendel's time, hundreds of experiments with both plants and animals have corroborated his results. His laws of heredity are constantly referred to. These are: First, *Principle of unit characters.* The organism is an aggregation of characters which are inherited as an entire unit and

not partially. Second, *Principle of Dominance.* When contrasting unit characters are present in the same parent (zygote) they do not blend but one is dominant and appears wholly developed, while the other is not apparent, it is recessive—one would not know of its presence. It reappears in breeding. Third, *Principle of Segregation.* Every germ cell is "*pure*" as far as any given character is concerned. When hybrids form germ cells these are of two kinds as far as pairs of contrasting characters are concerned. One half have something which will produce one of these characters, the other half have something else that will produce the other character. The zygote is a double being in all its cells, its gametes are single.

But an organism is an aggregation of many unit characters. It is possible to see what happens when interbreeding from two, three, or more pairs of characters takes place. The work becomes complicated as the number of pairs of contrasting characters is increased. Mendel crossed yellow, round-seeded peas with green-wrinkled. Yellow is dominant to green, and round to wrinkled. All the hybrids were *yellow-round.* But inbreeding of these hybrids produced four types of peas. Yellow-round, yellow-wrinkled, green-round, and green-wrinkled, and in this proportion: 9 : 3 : 3 : 1. There would be four types of sperm gametes and four types of egg gametes and the experiment could be expressed in this way:

Male gametes YR : YW : GR : GW
Female gametes YR : YW : GR : GW

Zygotes				
	YR YR	YR YW	YR GR	YR GW
	YW YR	YW YW	YW GR	YW GW
	GR YR	GR YW	GR GR	GR GW
	GW YR	GW YW	GW GR	GW GW

There are 16 possible combinations and these are called *genotypes*. But recessive characters are latent in combination with dominant so only 4 types of different-looking peas

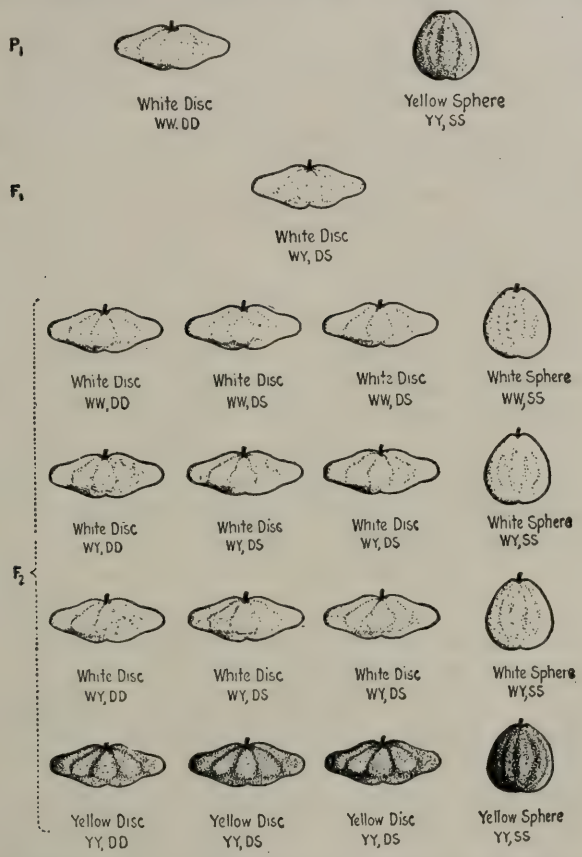

FIG. 336.—MENDEL'S LAW OF INHERITANCE WHERE TWO PAIRS OF CHARACTERS ARE INVOLVED.

In summer squashes, disc shape in fruit is dominant over sphere shape and white color over yellow. A white disc crossed with yellow sphere gives an *F*1 generation, all of which are white disc. When these are inbred, the *F*1 plant produces an *F*2 generation which is about $\frac{9}{16}$ white disc; $\frac{3}{16}$ white sphere; $\frac{3}{16}$ yellow disc and $\frac{1}{16}$ yellow sphere. (From Sinnott's Botany—Principles and Problems.)

appear. These are called *phenotypes*. There are 9 yellow-round, 3 yellow-wrinkled, 3 green-round, and 1 green-wrin-

kled out of every 16 seeds. Incidentally, one seed out of every 16 is pure yellow-round, one pure yellow-wrinkled, one pure green-round, one pure green-wrinkled. These would breed true in successive generations for they are self-fertilizing. This has all been worked out according to the laws which Mendel formulated (Fig. 336.)

Now it will be seen in this case of two contrasting characters that there are four kinds of male gametes and four kinds of female gametes. This in each case is the square of the number of contrasting characters. The number of zygotes is the square of the number of gametes or the gametes × gametes. The number of kinds of germ cells is " 2 " raised to the power which represents the number of contrasting character pairs and the number of possible combinations would be the square of this. Thus, if one were to follow out inheritance in case of three pairs of contrasting characters, there would be 2^3 or eight male gametes and eight female gametes and 64 genotypes. If we interbreed tall-dwarf; yellow-green; and round-wrinkled peas there would be 27 RYT : 9 RYD : 9 RGT : 9 WYT : 3 RGD : 3 WYD : 3 WGT : 1 WGD. There is only one pure recessive.

If we interbreed Mendel's seven pairs of contrasting characters there would be 2^7 male gametes or 128 and the same number of female gametes. The number or combinations would be 128^2 or 16,384 genotypes, although they would not all look different (phenotypes) since many would contain a recessive character.

Not only does this show facts and principles of inheritance, but it demonstrates the opportunity for variation that is present in sexual reproduction. Any organism is an aggregation of many times seven characters, yet with only seven characters mentioned above, there would be over 16,000 genotypes. With only fifteen characters there would be over one million genotypes.

But soon modifications to Mendel's discoveries were found. Correns found that when white flowered Mirabilis, the four-o'clock, is bred with a red-flowered variety, all the hybrids in the first filial generation had pink flowers, and

that when these were interbred, the flowers appeared in this proportion: 1 white : 2 pink : 1 red. A presence-absence hypotheses was devised to explain this. For example, tall peas possess a factor for tallness and dwarf peas have an absence of tallness. When both gametes carry a similar positive dose the zygote gets a double dose and is duplex, when only one gamete carries a dose, the zygote gets a single dose and is simplex, when neither gamete has a positive dose then the zygote gets no factors of this sort and is nulliplex. Let A = positive factor and a = absence of this factor; then (1) gamete $A \times$ gamete A = zygote AA, duplex; (2) gamete $A \times$ gamete a = zygote Aa, simplex; (3) gamete $a \times$ gamete a = zygote aa, nulliplex. Then it is asserted that if a character comes from one parent alone it is not fully developed. Thus white-flowered Four-o'clock are nulliplex; red-flowered forms are duplex. Cross them and result falls under category (2) or simplex; i.e., $A \times a = Aa$ or in this case, pink.

Walter lists nineteen investigations in heredity between 1903 and 1908 involving eight kinds of plants and eleven kinds of animals (including man) showing operations of Mendel's laws. It is of interest to list a few instances found in human heredity.

1. *Achondroplasy is dominant over normal.* Achondroplasy is a type of dwarfism where the trunk and head is normal in size but the limbs are short.

2. *Normal size is dominant over true dwarfs;* i.e., where all parts of the body are proportionately small.

3. *Brachydactyly is dominant over normal.* In brachydactyly the fingers are short, i.e., with fewer phalanges.

4. *Polydactyly is dominant over normal.* In polydactyly there are extra digits.

5. *Hereditary eye cataract is dominant over normal.*

Morgan says: "The evidence shows clearly that the character of wild animals and plants, as well as those of domesticated races, is inherited both in the wild and in the domesticated forms according to Mendel's Law."

Attention has been called to the fact that the microscopic germ cells form the only bridge between parent and off-

spring. If parental characters reappear in offspring, then those characters must have had some material representation in the germ cells. But what part of the germ cells? Observation shows that offspring inherit from father as well as mother. The part of the sperm cell that unites with the egg is almost entirely nucleus and is for the most part concentrated chromatin. This indicates that characters of mature offspring are due to substances possessed by the chromatin. Reference to the peculiar phenomena taking place in spermatogenesis and oögenesis tend to confirm the idea that it is the chromosomes that are involved. Mendel's explanation is surprising because he knew nothing of this. The definite substance in the chromatin that produces a definite character in the offspring is called a determiner, factor, or gene. It is but a part of a chromosome.

Mendel's explanation of the mechanism of heredity is in line with this hypothesis of the gene. In crossing yellow-round seeds with green-wrinkled seeded peas, color is inherited independently of smoothness of coat. This indicates the same conclusion. Morgan and his co-workers have investigated the inheritance in over a hundred characters in Drosophila, the fruit fly. These are characters inherited in a very definite way according to the Mendelian plan Moreover, they tend to arrange themselves in four groups. When one character of any group appears in the offspring as a result of crossing them, other members of the same group tend to appear also. Also any character of a group seems to be inherited independently of any member of the other groups. Now if genes are components of chromosomes, then one would expect just what is stated above. In germ cell formation entire blocks of chromomeres are parceled out to the sex cells. Associated genes would be separated together. The fact that there are four chromosomes in Drosophila further strengthens the view. Moreover, the painstaking researches of Morgan and his co-workers goes so far as to indicate that in each chromosome the genes have definite spatial relationship in a linear series. But there is no relation between this spatial relationship of genes in chromosomes and parts of the adult body.

The phenomenon of linkage is evidence favoring the hypothesis of linear arrangement of genes in a chromosome. Sometimes two characters seem to go together in inheritance. A common example of this is sex inheritance. It has been found in a number of cases that the body cells of the male have one more chromosome than an even number. This extra chromosome is known as the "X" *chromosome* or *sex chromosome.* It has nothing to pair with at synapsis and all of this chromosome passes over to one of the two secondary spermatocytes. So two groups or sperm are formed. In one group the "X" chromosome appears. The other group does not have it. In such cases the female body cells have two of these "X" chromosomes so that in oögenesis each egg gets one. The female has an even number of chromosomes and one more than the male. It is believed that there are forty-eight chromosomes in body cells of women and forty-seven in men. All human eggs contain twenty-four chromosomes. But there are two classes of sperm and these occur in equal numbers, one group with twenty-four chromosomes and one with twenty-three chromosomes. In fertilization each type of sperm would have equal chances. So that 50 per cent of all zygotes formed would possess forty-seven chromosomes and 50 per cent would have forty-eight chromosomes. Something similar has been demonstrated in many cases. It does not follow that this entire "X" chromosome has to do with sex alone. It should be remembered, moreover, that in determining sex a number of genes are probably involved, for the anatomical and physiological differences between males and females in man, for example, are many. It is not always a matter of an odd chromosome, sometimes it is a difference in shape.

A number of cases of association of other characters with sex illustrates the phenomenon of linkage. This is seen in inheritance of a form of color blindness called *Daltonism.* When such a color-blind father marries a normal woman, he transmits this defect through normal daughters to half of his grandsons but not to his granddaughters. In the rare cases of color-blind women marry-

ing normal men, the sons inherit the blindness from their mother and transmit it to half her grandsons and granddaughters. If it is assumed that the gene for color blindness is " linked " with the gene for " sex " developing in males when it is simplex (X) or in females when it is duplex (XX); then it works out according to the following scheme in which " XO " represents the simplex gene of male sex and " XX," femaleness and the color-blindness gene associated with the sex gene X; i.e., to be color-blind, the genetic constitution of the male would have to be ~~X~~O or of the female ~~XX~~.

Parents

~~X~~O——XX = Color blind man marries a normal woman.

Egg cells X X = All egg cells the same from the mother.

Sperm cells ~~X~~ O = Two kinds of sperm cells from the father.

~~X~~X	XO
~~X~~X	XO

These would combine thus:

2~~X~~X + 2XO = Children, none of whom is color blind.

Eggs ~~X~~ X

Sperm X O

~~X~~X + XX + ~~X~~O + XO

If intermarriage of these types occurred their germ cells would be as shown at the left and The mating would be as shown at the left. None of the granddaughters would be color blind and only half the grandsons. Moreover, color blindness in one-half grandsons would be inherited from the daughter of the color-blind grandfather although she is not color blind.

The above shows what the mating would be theoretically. Actually, it is as shown. Now what would occur when a color-blind female marries a normal man? Theoretically again it would work out as follows:

XO = male parent; ~~XX~~ = female parent. (1).

X O Male germ cells.

~~X~~ ~~X~~ Female germ cells. (2)

$X\overset{\times}{X}$ — $\overset{\times}{X}O$ The following combinations would take place (3).
$X\overset{\times}{X}$ — $\overset{\times}{X}O$

50% $X\overset{\times}{X}$ + 50% $\overset{\times}{X}O$ The sons are color blind and (4) the daughters are not color blind but have the gene for color blindness on one X chromosome.

Egg cells X $\overset{\times}{X}$
Sperm cells $\overset{\times}{X}$ O

If intermarriage of types like the above took place the germ cells would have this composition.

$\overset{\times}{X}X - \overset{\times}{X}\overset{\times}{X} - XO - \overset{\times}{X}O$ The results would be 50 per cent of the daughters color blind and also 50 per cent of the sons color blind.

Studies in inheritance also indicate further peculiarities of the chromosomes. It has been stated that genes seemed to be linked in a linear series in certain chromosomes. Inheritance of these genes would depend on whether the germ cell received this or that portion of a chromosome in maturation. But, in certain cases, the offspring seem to inherit new combinations made up of parts of groups of characters. In synapsis it is observed that sometimes chromosomes appear to twist around each other and that when separation occurs they part company in pieces—fragmenting at the place of twisting as shown in the following three figures. This explanation is known as "*crossing over.*" (Fig. 337.)

Morgan and his co-workers have calculated the number of genes in the chromosomes in the germ cells of Drosophila to be about 7500, but warn that this be not taken too literally. Morgan says that in his opinion, "The problem of heredity has been solved. We know how the factors carried by the parents are sorted out to the germ cells. The mechanism of the chromosomes offers a satisfactory solution to the traditional problem of heredity."

Formerly breeders used to work blindly toward desired results. To-day, applying Mendelian principles results are secured earlier and more surely. Some illustrations of the practical application of these results have been the production of a variety of wheat which possesses the good

qualities of several varieties, such as large yield, high protein content, resistance to rust disease, beardlessness, short growing season; corn with more sugar or starch; sheep with more wool and better meat; hens that lay more eggs; cows with more milk.

An enormous amount of work had been done in agricultural experiment stations during many earlier years in attempts to produce better crops and better animals by improving external conditions. There have been many disappointments. One reason is that the hereditary constitution of the seed or parent animals was not taken into consideration. Prior to 1900, practically nothing was known of the Mendelian principles or laws involved. The combination of genetics with environmental science is necessary to solve these problems. When a breeder after a few years (depending on the time between mating and sexual maturity of his material) is satisfied that his new combination produced by breeding is pure or homozygous with regard to the several characters, then he can be sure that the offspring will continue as the parents. Plant breeders do not have to go so far. By inbreeding they can produce a desirable phenotype and can continue to produce this by grafting. If allowed to breed, it would revert back to pure strain.

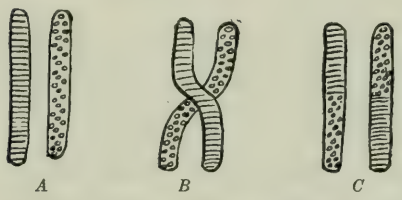

FIG. 337.—IN MATURATION, GERM CELL CHROMOSOMES COME TOGETHER.

A maternal with a paternal (*A*); at times they bend around one another (*B*); when they separate, they are often joined as indicated in (*C*). This is called crossing over.

Mendel happened to work with cases of alternative inheritance in which the children of hybrids were like one grandparent or the other. But there is also a Mosaic inheritance in which the offspring show clearly in part both characters, but without blending, or there is blending where the hybrids are a blend between the characters of the parents. These cases, it has been found, can be explained in harmony with Mendel's Laws.

A question which has received a great deal of attention, is as to just what characteristics of parents are inherited by their children. The answer of the geneticist is that the inheritance of the child depends on the *genes* it receives from the parents. Suppose these parents have grown up under entirely different conditions from their own parents. Do these new conditions modify their genes and produce different children? This question was critically examined by Weismann (Fig. 338) and discussed in a book on "The Germ Plasm," in 1893. In this he showed that germ plasm, or substance of sex cells, is the only material that passes from one generation to the next and that even the highest animals develop from a minute mass of *germ plasm* (fertilized egg); that early in development, germ tissue is differentiated and set apart from body tissue and that germ plasm is *not* influenced or affected by external factors. The body may be modified but these modifications do not affect the germ plasm, although in single-celled animals there is an unbroken continuity of somatoplasm from generation to generation, yet in metazoa, it is only the germ plasm that is continuous from generation to generation, and the body is only a carrier for the germ cells. The reason that offspring resemble their parents is because they both have the same general germ plasm. The germ plasm of the egg is not exactly like the germ plasm of the sperm. The mixture of these in fertilization brings about a new combination that has hitherto not existed. Weismann called this union of two germ plasms in sexual reproduction, "*amphimixis*," and showed that the purpose of sexual reproduction is to give variation. All the recent work in heredity bears out Weismann's theory of the germ plasm and it must be remembered that Weismann knew nothing

Fig. 338.—August Weismann, 1834–1914. Author of "The germ plasm," 1893; "The evolution theory," 1904. (Courtesy of Chas. Scribner's Sons.)

of Mendelian Laws. It is interesting to note that chromosomes were discovered in 1883 by Van Beneden and Boveri ten years before Weismann's Theory of the Germ Plasm appeared in English, and nearly two decades before the rediscovery of Mendel's Laws. (Fig. 339.)

Another century-old problem that is vitally associated with Genetics and can now better be understood, with Weismann's theory of the germ plasm in mind, is that of the *Inheritance of Acquired Characters*. This question is but one aspect of the question of the origin of variations and as such has to do both with evolution and heredity. It is well known that constant exercise or use strengthens or develops an organ, and constant disuse causes it to weaken and even to atrophy. A person with a moderate degree of musical ability and a liking for it may with constant practice become an accomplished violinist. At least, he becomes a far better violinist than he was at the start. A person may set out to learn to do wonderful acrobatic feats and after thorough training become adept at tumbling. There is no doubt about modifications taking place in an organism during its lifetime. But an age-old question is this: "Are these modifications inherited by the offspring?" The great exponent of the affirmative position was the Frenchman, Lamarck, in his "Philosophy of Zoology," published 1809. A contemporary (each unknown to the other) Dr. Erasmus Darwin, in England, held similar views. Later on even his grandson, Charles Darwin, accepted them and so did the philosopher, Herbert Spencer.

Fig. 339.—Gregor Mendel (1822–1884).

(Courtesy of "Genetics.")

The inheritance by the offspring of modifications occurring during the life of the parents is a phenomenon that, if true, would explain, many features of heredity and

evolution. Weismann, having arrived at his conclusions regarding the relation of the body plasm to germ plasm could see but one answer to the question and that was negative. If the body is a mere vehicle of the germ plasm and the latter alone continues from generation to generation, how could modifications in the body change the germ plasm? He granted that body cells can be modified, but he rigidly excluded any *corresponding* changes in the germ cells. He cut off the tails of male and female mice and bred them. For twenty-two generations of experimentally produced tailless mice, the offspring bore tails. Docking tails of horses and dogs for generations has not produced any tailless variety. As far as any improvements gained by education or training are concerned, it is common experience that each generation has to begin where its parents began. Nature (heredity) is more basic than nurture (environment). Favorable environmental conditions do not change the germ plasm. Only that which is in the germ plasm can appear in the offspring. It is a matter of genes. As Locy says, "There is not a single case in which the supposed inheritance of an acquired character has stood the test of critical examination." And Morgan affirms, "The evidence as to whether the effects of use and disuse are inherited is not in accord with Lamarck's doctrine."

Now in spite of Weismann's extreme position, it has been shown that germ plasm can be changed, but not in the simple direct manner as claimed by Lamarck. The ovaries and testes are nourished by a somatic fluid—blood. Suppose this blood contained a toxin, or suppose it were deficient in food. Would not such condition tend to produce germ cells of different potency than if the blood were normal? Even Weismann was obliged to admit something of this when he developed his idea of the complexity of the germ plasm. Protoplasm is plastic—its chief characteristic is its response to external stimuli and the resulting modification. As a result of thousands of years of such stimuli and modifications in response to them any germ plasm has come to be what it is; that is why it has become so complex. But it does not follow that any given modifications in the body produce corresponding modifications in the germ plasm.

That external stimuli can modify the germ plasm is shown by the experiments of Stockard. He bred normal male guinea pigs with females that had been repeatedly intoxicated (poisoned) with fumes of alcohol, and also the reverse, mating normal females with abnormal males. The offspring were not normal; they showed physical deformities of one sort or another, the number in a litter was less than the average, often some were born dead. In this case the toxin in the blood circulated through the sex glands and modified the constitution of the genes.

This may all be true and yet there is no explanation as to just how new genes are formed. It will be shown later that the appearance of new characters in populations that did not previously possess them are known. In these cases there is no evident relationship between them and the body—or the environment.

There has been an age-long debate on the relative importance of heredity and environment. Improvements in domestic plants and animals have been found possible only by combining the effects of heredity *and* environment.

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CHAPTER XXVIII

ADAPTATION AND EVOLUTION

Adaptation.—The adaptations of organisms to their environment furnishes a fascinating and extensive field for observation. To the biologist the constant adjustment involved is one of the outstanding features of living nature. He sees it in the gnarled and wind-beaten cypresses that persist through the years on the barren rocky promontories near Monterey, California. He sees it also in the whale, an air-breathing animal, that is at home in the expanse and depths of the ocean beyond. That organisms are fitted to their environment is almost axiomatic. The environment acts as a sort of examining board. If the organism passes the test it survives; if it fails, it dies. And there are gradations between complete extinction and full-rounded, successful life. An interesting comparison is that of many kinds of human careers. It is often said that the course of a life is moulded by circumstances. This is but a particular application of the great biological law that the organism is changed by the environment.

Henderson in his book on " The Fitness of the Environment " has called attention to another side of the question, which belongs to the realms of geology, physics, and chemistry. The environment itself changes. It has had a history and an evolution of its own. As it exists at present, it is just what makes that peculiar complex of matter and energy, called protoplasm, possible. The properties of carbon, hydrogen, oxygen are absolutely essential and carbon dioxide is the only compound that could serve as it does. Change these things profoundly and life is obliterated; modify them ever so slightly and living forms change. Think of shore conditions and those of the great ocean; of surfaces or depths; valleys and mountains, fresh

water, brackish water; ocean waters, the dense waters of Salt Lake; deserts, marshes, forests, plains, everywhere variations innumerable, but at the same time alike in fundamentals, such as water, oxygen, carbon dioxide and nitrogen compounds.

This connection with the environment is more direct in the case of plants. They cannot move around to other surroundings. The animal can try this or that environment and may settle down wherever it is most suitable, i.e., " the carp lives in muddy ponds or muddy, sluggish streams; the trout in clear, swift waters."

In some cases the adjustment is merely a case of the organism selecting the most suitable environment. In others, a change takes place in the animal itself. The ancestors of some animals had teeth, but these degenerated as the race grew old and the jaws developed bony plates, thus permitting the use of shell animals for food and prolonging the life of the species.

All forms are mutually interdependent. An extreme example of this assertion is that if gooseberry and currant bushes were destroyed, the fungus that destroys pine trees with the disease called the " White Pine Blister " would probably largely disappear. The liver fluke would also probably disappear were there no sheep or land snails. It has been stated that " all fish is diatom " and a reduction of diatoms would certainly modify the fish population of the sea. A fungous disease on potatoes caused a famine in Ireland. More obvious still is the profound effect on animal and plant life due to environmental changes of an inorganic sort. The geologist describes great cataclysmic changes in organic life when glacial floods encroached upon the tropics. Widespread removal of forests completely alters the character of a country. Forested, it is fertile and agriculturally potential; deforested, it may become an arid, non-productive waste. It has been claimed that the presence of forests determines the amount of rainfall in certain regions.

It is quite well established that structures do not determine function, but rather that structures depend on the

interaction between environmental conditions and organic functioning. The presence of a functioning sensory and motor nerve determines the full development of an organ such as the arm. Nerves keep the organ in touch with the environment, so that functional activity is essential to adaptation. H. F. Osborn believes that the determiner of adaptations is the environment. He divides adaptations into two great groups as follows:

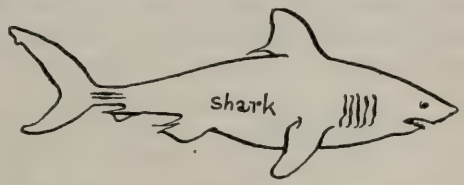

FIG. 340A.—A CONVERGENCE IN EVOLUTION.
The shark's body is fitted for aquatic locomotion.

First, where unrelated types assume similar forms as a result of adaptation to the same environment. This is known as the *law of convergence of form.* It is amply illustrated by Vertebrates. Examples of this law are: (1) Adaptations for rapid swimming. These affect chiefly superficial structures. The shark, (Fig. 340*A*) the extinct Ichthyosaur, (Fig. 340*B*) the porpoise (Fig. 340*C*) all have a spindle-shaped body, bulky in front, a pointed nose, a propelling tail, a dorsal fin which acts as a keel, and anterior appendages used for balancing. The internal anatomy is typically elasmobranchian in the shark; reptilian in the ichthyosaur and mammalian in the porpoise. (2) Adaptations for flight, illustrated by insects, birds and bats. The flying apparatus differs in structure, but functions similarly in each case. Other types are shown by the similarity of form assumed by different classes

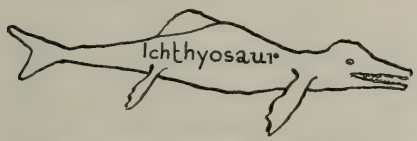

FIG. 340B.—THE ICHTHYOSAUR.
An ancient, aquatic lizard, approximates the shape of the shark.

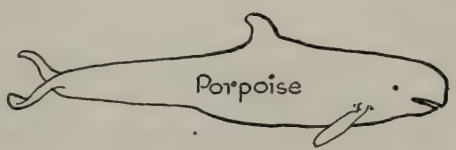

FIG. 340C.—THE PORPOISE.
A mammal again is similar to the shark in body form.

of animals in adaptations for running, climbing, burrowing, desert dwelling, and deep-sea dwelling.

Second, members of any one group or closely similar groups may in time adjust themselves to a great variety of environmental conditions and the organs of the body are consequently modified as far as necessary to effect this end. An illustration of this was given in the discussion of Dino-

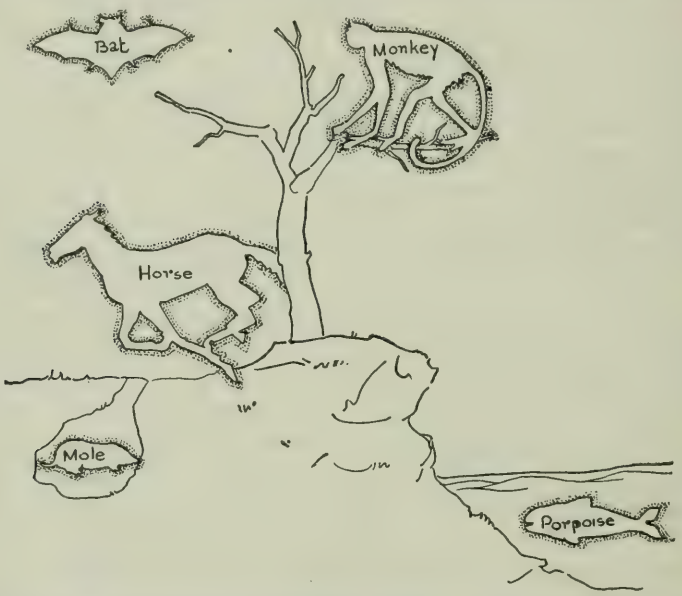

FIG. 341.—ADAPTATION TO DIFFERENT MODES OF LIFE AMONG MAMMALS.

The Bat, aerial; Monkey, arboreal; Horse, cursorial; Mole, fossorial; Porpoise, natatorial.

saurs. Among Mammals there can be found (Fig. 341) running or cursorial types; burrowing or fossorial types; climbing or arboreal types; swimming or natatorial types; flying or aerial types. There are special adaptations for defense or obtaining food. Structures especially adapted for vigorous combat appear in Carnivora. These structures are concerned in both food getting and self-defense. The sting of the bee is a weapon of defense, the sting of the solitary digger wasp is associated with providing food for

the unborn young. The torpedo ray, an Elasmobranch, has muscle tissue in the pectoral fins which acts as a storage battery, giving an enemy a severe electric shock. The mammary glands of Mammals are modified oil glands, a special adaptation for feeding the young. The gorgeous tail plumage of the male peacock or the antlers of the stag are modified structures or adaptations used in bloodless or bloody competition with other males for supremacy.

Parasitic life has brought about extensive modifications resulting in adaptations of dependency. Organs of locomotion and sense organs, no longer needed for adjustment, disappear. This is also true of certain organs of metabolism. The digestive tract may vanish. In the case of parasites, which in their life-cycle inhabit different hosts, the chances of completing the cycle are reduced. To meet this situation an enormous number of eggs and sperm are produced. In some cases the early development of some parasites is similar to related independent forms, but with the assumption of the parasitic life, degeneration later occurs. A comparison of free-living individual Hydras with the hydranths of an Obelia colony illustrates the modifications brought about by adaptation to a sedentary colonial life. The change in a tunicate from a free-swimming larva to a sessile adult illustrates another way in which a sedentary life can be attained. The study of a bee colony indicates the production of differential types from a primitive single type.

Interesting adaptations are those of *commensalism* in which two different forms live in an association that is without harm to either. A remarkable case of this sort is the peculiar fish, Fierasper, that lives in the gastric cavity of a Sea Cucumber. The fish hides there with body concealed and only the head out. It darts from security, now and then, after prey. The hermit crab occupies the cast-off shell of some sea snail. The body wall is soft, as the usual exoskeleton is not needed. Sea anemones become attached to the snail shell and cover it with a colony formed by budding. The crab is protected or hidden from sight by the anemones. The anemones share in food that drops

from the mouth of the crab. This is a case of commensalism. Another type of association is more intimate and is called *symbiosis*. The green color of Hydra viridis is due to the presence of small green Algae. This is an association in which both organisms are vitally necessary to the life of each other. The bacterial Flora of the human large intestine is also a possible example of symbiosis. These bacteria are not altogether parasitic, for they help in the process of digestion and absorption of food. Each member of this association contributes to the life of the other.

Many tree-living forms such as katydids, spiders, par-

FIG. 342.—KALLIMA, BUTTERFLY FROM INDIA.

Protective resemblance. At left, it is shown resting on a twig. When its wings are folded it looks like a dead leaf. At right, wings expanded, a very different appearance.

rots, are green in color. Against the green background they would be passed by unnoticed. The polar bear and other Arctic animals are white; the ptarmigan assumes a white coat in winter; the flounder changes its color to blend with the color of the bottom; Kallima (Fig. 342), a butterfly from India, folds its wings as it rests on certain twigs and looks very much like a dead leaf or a twig. The walking stick resembles a dried twig. These are illustrations of protective resemblance. Protective resemblance is the agreement in color or form, or both, between an organism and some part of its environment. It often results in the organism being inconspicuous. No less striking adaptations are those of *mimicry*, which is a special

kind of protective resemblance. In this sort of adaptation a defenseless species apparently secures protection by possessing a close resemblance to some form that is well protected (Fig. 343). The defenseless forms are " mimics " and they resemble certain " models." Wasps and bees are protected by their stings. They have distinctive colors or markings by which they are recognized, with the result that they are let alone. Certain harmless flies, moths and beetles look just like or mimic such protected bees and wasps. Some of them also " buzz " like bees. Certain edible butterflies mimic other bad-tasting varieties.[1]

FIG. 343.

A, is Heliconius, a butterfly which is the model for *B*—Mechanitis, another species which mimics *A*. *A* is nauseating to taste and birds avoid it. *B* is not, but is protected because it resembles *A*. Both are from Honduras. This is an example of mimicry.

Ecology is defined as that branch of Biology which studies and explains the relation of organisms to their environment. From this point of view it is merely another name for the "*science of adaptations.*" It has sometimes been called "*Bionomics.*" The ecologist is not directly interested with the question of evolution. He studies the relation of plants to the environmental conditions of soil, water, and temperature; the relation of the animal population to the plant population; the interrelationships of the various kinds of animals in this association. On the whole, it may be stated as a general principle that organisms are found in a particular environment as a result of responses to stimuli. The results are innumerable. If the response

[1] Those not having access to museum material illustrating color adaptations can find very fine pictures of them in Metcalf's "Organic Evolution."

is positive, the organism finds itself in a favorable environment; if negative, it does not flourish or it perishes. The inhabitants of a certain locality are present because their response to stimuli has been favorable in that locality.

The ecologist is not always satisfied with a mere description of what is found in a locality. He attempts to go further than this in order to ascertain the reasons for the adaptations. An illustration of this method is given by Fasten who studied the environmental reactions of a parasitic copepod (crustacean) Lernoeopoda, which passes the greater part of its life on the gills of the brook trout, *Salvelinus fontinalis*. He discovered the conditions under which the copepod becomes attached to the gills. It illustrates how delicate is the interdependence of conditions in determining adaptations. This copepod hatches from the egg as an active, free-swimming larva. It is quite heavy in proportion to its size and sinks to the bottom when not swimming. In strong light, it swims near the surface. As the light decreases, its activities diminish. At night it gives no reaction and sinks to the bottom. The young brook trout swim near the surface of the pond in the daytime seeking food, and at night they settle to the bottom. If pieces of the gills of other fish are placed in the water this has no effect on the copepods. If, however, pieces of the gills of this particular species of trout are placed in the water then unusual swimming movements follow and if the copepods come in contact with the gills, they at once attach themselves. They are attracted by some stimulus given out by the gills. But it is largely their response to light which leads to successful adaptation to their environment.

Again, the biologist is especially interested in adaptations because he believes that in the course of ages of adaptations new forms have arisen, i.e., new species have originated from old. Copepods are older than trout, but this particular parasite just mentioned may be a new species that may not even be as old as the trout.

The study of adaptations has led students to the con-

clusion that from the constant interaction between ever-changing external conditions and forces on the one hand, and the living organism on the other hand, there has resulted modifications in organisms. And that due to adaptations of the organism to the environment, as a result of which these modifications have been produced, new and more complex and more fit organisms arise. This is *Evolution.*

Evolution.—Human comprehension of space includes ideas of the wide world, the planets, the sun and solar systems. It ponders upon such matters and also philosophizes about the future and about the past. It is characteristic of the human mind to want to know. Science provides it with means to distinguish between what is true and what is false. Knowledge, however, is limited and this hunger and thirst are often satisfied with faiths that have no basis in knowledge. Science is concerned with what is known, faith is a belief in the unknown.

Until recently it has been believed that there exist two phenomena, matter and energy, or force, and that between these two there is an ever-restless, ceaseless change. Recent investigations indicate but one, namely energy and also that *matter is a form of energy.* The astronomer has developed a theory that from simple beginnings there has grown to be the astronomical world of to-day. He says that the change still goes on. The geologist begins the study of the earth as a whirling molten ball rotating in unseen harness about the sun. The story is one of gradual evolution through millions of years, beginning with a gaseous mass separated from the sun to the complex structure of our own time. The old idea of the earth was that it was a flat and saucer-shaped mass resting " upon the waters " which surrounded it on all sides; that the sky was a hemispherical dome which rested on mountains around the edge. The stars were like lamps in a ceiling, and there were also " the windows of heaven." The " sun came forth " through one of the Eastern windows in the morning and left by another in the West at night. These were beliefs, not knowledge, and, after all, are not as awe-inspiring as the actual truth:

Concerning living things that exist to-day, one may entertain in general two ideas. One is that they were all created, just as they are now, not so long ago and in the very short period of a few days. Such ideas occur in the writings of many ancients who merely wrote what they believed to be true. But as the astronomer gradually developed his idea of the history of stars, sun and planets, and as the geologist investigated the history of the earth, so the student of animals and plants developed the idea of *organic evolution*, which is merely the idea of gradual development from generalized or simple forms to complex organizations, and that throughout the entire course of these modifications natural forces have been responsible for the changes and the results. The only rational explanation of the astronomical universe rests upon this idea, the only rational explanation of geology rests upon it. The physicist and the chemist find that they must extend it to their fields in order to arrive at a satisfactory explanation of physical and chemical phenomena. Evolution is the most outstanding conception of Natural Science. It is evidenced in the history of education, and the student of religions also finds it in his field.

The theory of organic evolution holds that from the time when living matter was first formed, a succession of increasingly complex organisms have gradually come into existence. Some old forms have become extinct and new forms have appeared. With increasing specialization has come more perfect adaptation to the conditions of the environment. According to ancient belief, all forms now existing have existed side by side since their creation. The evolution theory, however, likens organic life to a tree whose trunk represents primitive simple forms. This branches out into slightly more special forms, and still other branches follow from these. New and younger branches represent newer and younger and more specialized types or species. The members of a species resemble each other more than they do anything else. Offspring for the most part resemble their parents, and this characteristic carries with it another characteristic, namely, that the individuals of a species are mutually fertile.

There is no observational evidence of any kind in support of the simpler primitive belief in *special creation.* There is a vast accumulation of circumstantial evidence for the theory of *organic evolution.* The theory of the astronomical universe, the geologist's theory of the formation of the earth, the atomic and electron theories of the chemist and physicist, are also based on circumstantial evidence. The so-called scientific explanations of these phenomena are merely conclusions which are in harmony with the observed facts and no body of facts contradicts them.

There are at least seven great classes of facts that bear witness to the truth of organic evolution. These are: (1) Palaeontology, (2) Geographical Distribution, (3) Classification, (4) Comparative Anatomy, (5) Embryology, (6) Blood tests, and (7) Genetics.

(1) *Palaeontological Evidence.*—This consists of facts discovered in a study of fossil animals and plants of different geological ages, and constitute very strong evidence for the theory of evolution. The history of the horse, of the camel and of the elephant have been carefully worked out and testify to this conclusion. Some of the general observations are: (1) Organisms of the newest (highest) strata are most like living forms and also they are the most specialized. (2) Organisms of the oldest (lowest) strata are least like the living forms and they are more generalized. (3) There is a gradual progression from the lowest (oldest) to highest (youngest) strata from simple generalized forms to complex specialized forms. (4) From generalized relatives of specialized forms arose living representatives of those groups. (5) Many types of plants and animals appeared at certain early times, flourished for ages, becoming more and more specialized, then became extinct. (6) At the end of one geological age when great earth and climatic changes took place, new groups arose and these became the dominant group of the next age. (7) Most of the Invertebrates had already undergone a great part of their evolution by the time fossils are first found. (8) Since skeletal structures and teeth serve as good indices of animal

organization and since these parts of Vertebrates apparently lend themselves to a more certain preservation as fossils, the evolution of Vertebrates is naturally better known than that of other forms. Vertebrate palaeontology

FIG. 344.—EVOLUTION OF THE HIND FOOT OF THE HORSE.

Beginning with the left, Eohippus, Mesohippus, Miohippus, Merychippus, Hipparion, Equus. (After Osborn and Amer. Mus. Nat. Hist.)

(Fig. 344) presents a wealth of evidence for the theory of organic evolution including observations bearing on the *evolution of man.*

(2) *Evidence from Geographical Distribution* is given by many peculiar and puzzling cases of distribution of plants

and animals that can be explained only by proceeding on the theory that they are what they are because of the operation of organic and geological evolution. Some forms have the widest distribution and are not checked by any barriers. Examples are Man, certain other Mammals, and Birds. Other forms once of wide distribution became isolated in certain localities. Representatives of such isolated forms still continue to exist much the same as formerly. This is illustrated by the giant tortoises of the Galapagos Islands. Darwin found that the existing Edentates (sloths, armadillos and anteaters) are practically limited to South America. These are a somewhat generalized ancient type of Mammal. He also ascertained that fossil Edentates similar to these living forms are also typically South American. So he argued that these modern Edentates have descended from the more ancient forms and that certain modifications from the original type took place.

The peculiarities of Fauna and Flora of oceanic islands, now separated by hundreds of miles of water from the mainland, are understandable only by proceeding on the hypothesis of organic evolution. Why should the Fauna and Flora of any such island have peculiar indigenous characteristics? A description of two instances of this is but a sample of a vast field of accumulative observations and explanations. (*a*) The Galapagos Islands are a group of Islands varying in size and located about six hundred miles west of Ecuador. They are volcanic in origin. The water about them is very deep. It was after studying the Fauna of these islands that Charles Darwin first conceived the idea of evolution. He observed that in general the Fauna and Flora were distinctly American. However, the islands differed markedly from the mainland of South America in climate and in geological and other conditions. The Galapagos Islands and the Cape de Verde Islands, west of Cape Verde, Africa, resemble each other in climate, in soil, etc., but are entirely different in Fauna and Flora. The Fauna and Flora of the Cape de Verde Islands resembles that of Africa. The Galapagos Islands are located in a

calm region where turbulent storms do not sweep. Other islands such as those of the Azores and Bermudas are further away from the mainland, but to them are carried seeds of plants, insects, birds and possibly other animals in drift-

FIG. 345.—DISTRIBUTION OF GALAPAGOS ISLAND FINCHES.

The Galapagos Islands were united to the mainland long ago. The evolution of different species and subspecies has taken place since the separation from the mainland and the formation of the archipelago of islands. Darwin says: "Seeing this gradation and diversity of structure in one small intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends"—"we seem to be brought nearer to that great fact—the first appearance of new beings on the earth." (Amer. Mus. Nat. Hist.)

wood from the mainland. Both in Fauna and Flora the Galapagos Islands contain species peculiar in special characters to these islands. The land birds, however, are allied in general characteristics to the South American forms. (Fig. 345).

They show gradations from identity with the mainland forms to distinctly peculiar forms. There is evidence that, ages ago, the Islands were connected by land with the continent and their Fauna and Flora were then like that of South America, and that later the islands became isolated from the mainland by a wide deep gulf. A certain population of animals and plants was thus stranded and during the following ages from these original species special peculiar types developed under the geologic and climatic and other conditions which are peculiar to these particular islands. Such an explanation makes clear the observed facts.

b. Marsupials constitute almost the only group of mammals indigenous to Australia. No marsupials occur in Asia, Africa, or Europe. Opossums, relatives of the Australian marsupials, are found in America. All the higher types of Mammals existed in the Eocene or Cretaceous, but there are no traces of them in Australia. Australia must have become separated from Asia in the Mesozoic era. During this period fossil remains of generalized types of Mammals indicate that they were the ancestors of the marsupials and that they were quite widely distributed. Some of them entered what is now Australia about Jurassic times (early Mesozoic) and when later Australia was cut off from the mainland they remained isolated from any higher competing type. Neither the extent of land nor variation in conditions favored extreme evolution of new classes. Evolution of a minor sort took place for there are a number of kinds of marsupials present. Some are rodent-like, some carnivorous, some herbivorous, some insect-eaters, thus indicating that in spite of the sameness of the conditions, there was an evolution on a very restricted scale of the same sort that took place on the continents with their greater variations in conditions. Fossil Mammals of the higher orders are not found in Australia. By the time they had evolved elsewhere a deep gulf separated them from Australia. The American opossums are somewhat specialized descendents from generalized marsupial ancestors, some of which became isolated in Australia in early times.

3. *Classification.*—Linnaeus (Fig. 346) about the middle

of the eighteenth century, published the "*Systema Naturae*" which presented an orderly classification of plants and animals. In this scheme of classification Linnaeus devised several kinds of groups extending from the most general and inclusive to the more circumscribed and specialized. For example, the European wolf belongs to the species *lupus*. But several species of wolf-like animals constitute the genus *Canis*. Linnaeus adopted the scheme of combining the name of the species with that of its genus to identify it. The house dog is Canis familiaris. Wolves, foxes, hyenas, jackals all belong to the *family* Canidae, all being wolf-like or dog-like forms. The Canidae, Felidae (cat family), Ursidae (bear family), and the aquatic seals and walruses constitute the *order* Carnivora, or flesh-eating animals. The Carnivora, Cetacea (whales) Rodentia (gnawing form, like rats), etc., form the *class* Mammalia which are all fur-bearing.

FIG. 346.—LINNAEUS, 1707–1778. TAXONOMIST.

Originated Binomial System of naming animals and plants.

The Mammalia, Aves (Birds) Reptilia, etc., have an endoskeleton with a jointed backbone and hence are members of the Subphylum Vertebrata. Vertebrata, Mollusca, Arthropoda, etc., constitute the *Kingdom Animalia*.

Linnaeus at first thought that each species was a separate creation and, in fact stated, that all the species he described had existed since the beginnings of life. He thus denied any blood relationship between various species. The principle which Linnaeus claims to have adopted was arbitrary and artificial. To a person familiar with many examples of any given species, the rigid application of his simple rule becomes

impossible for the outstanding phenomenon impressing one who collects great numbers of any one kind of animal with the fact that individuals vary from one another. If this type of animal has a wide geographical range, then specimens collected from the extreme limits of the range would undoubtedly have been regarded by Linnaeus as distinct and separate species. But when all the intervening forms are placed in order of geographical occurrence, it is easily seen that one grades by small differences into the other. This suggests that possibly the ancestors of this type started from a certain region and gradually spread in various directions and that due to natural causes, variations from the original type arose. It is often difficult to decide upon the exact number of species, certain large general groups should be divided into.

If we use the principle of descent with modification as a guiding principle of classification, the errors of the Linnaean artificial method of classification largely disappear. Whatever errors there are, are largely due to incomplete census of all existing or past existent forms. According to the Linnaean principle of classification, the various kinds of dogs, pigeons, horses, cattle, goats, sheep, etc., would have been recognized as special species. But Darwin's careful studies indicated that all these various present breeds were derived by man from one or two or at least from fewer ancestors than there are present-day breeds. Darwin describes an illustration of the formation of apparently a new species.

About the year 1420, a Portuguese sailor liberated some domestic rabbits descended from the European wild rabbit (*Lepus cuniculus*) on the small island of Porto Santo near Madeira. Conditions favored their persistence and multiplication in this island. In a human generation they were exceedingly numerous. To-day their descendants would be classed by Linnaeus as a separate species, i.e., as a special creation. In fact, Haeckel called it *Lepus huxleyi*. This *new species* has developed since 1420. Since Darwin's time the doctrine of descent with modifications has been accepted as the *guiding principle of classification*

and according to this way of looking at the animal world, all species belonging to the genus Canis are blood relatives, that is, all these various species have descended from a common ancestor whose general characteristics are the characteristics of the genus. All genera of the same family have had a common ancestor, similarly all families of the same order have had a common ancestor, all orders of the same class have had a common ancestor and so with the phyla.

According to this view, *all animals are related.* Those closely resembling one another are closely related and have not separated far from the ancestral type. Coelenterates remain more nearly like the ancestral Protozoa than do the Annelids, which in turn are more ancient because they are more simple and generalized than Arthropods, and so on. According to the Linnaean system, once a species was established it could not change. According to the Darwinian idea, more extensive knowledge often makes it necessary to change species, genera, or families into other groups.

A modern classification represents the taxonomist's idea of the descent of animals. It is a code or formula of the history of organic life. It undoubtedly has errors which its authors fully recognize as due to incomplete knowledge. Possibly we will never be able to acquire many of the missing links which have been lost long ago or have been completely destroyed. Modern methods of classification do not prove evolution, but rather establish the fact that a classification based on the hypothesis of organic evolution works out more harmoniously than any other guiding principle. It is interesting to note that the underlying idea of the Linnaean classification was that of descent relationship which he unconsciously adopted and yet he refused to admit the idea of descent with modification as being possible.

4. *Comparative Anatomy* furnishes evidence for evolution by a comparison of the structures of animals which reveals the fact that, in spite of their differences, they have many points in common. These resemblances indicate a common ancestry, and also that from generalized older

types were derived newer specialized types. Closely similar animals are nearly related, while less similar present-day animals with fundamental resemblances had a common ancestor long ago. This is the only argument that satisfactorily explains the facts of Comparative Anatomy. It is not necessary to restrict one's search to the Vertebrates for such evidence. But the anatomy of Vertebrates is more like that of man and such evidence is more readily comprehended.

The theory of evolution, of descent with adaptive modifications, makes clear the many facts of resemblance and

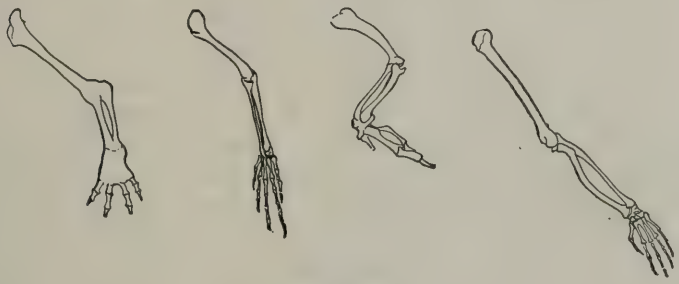

FIG. 347.

Fore limbs of *A*, Necturus; *B*, Iguana; *C*, Hen; *D*, Gorilla.

difference. How can rudimentary structures still present in many animals be explained other than as being remnants of what were once important structures in the ancestors of that animal? There are over a hundred of these vestigial organs present in the human body. Porpoises and pythons have remnants of the hind limbs inside the body. A study of the fore or hind limbs of different Vertebrates reveals modifications for better adaptation of a primarily generalized structure. The forelimb of a Necturus, a lizard, a bird, a bat, a dog, a cow, a chimpanzee and a man, all have the same general plan (Fig. 347), although modifications occur here and there.

This plan, however, is retained more closely where only a generalized use of the limb is demanded, when certain parts are absent, and certain other parts are decreased in

size while other parts are increased. These differences are explainable largely on the ground of special uses. Taking into account the results of comparison, it would be rational to conclude that tailed and tailless Amphibia are more closely related than any of them are to any Reptiles; that all the types of Reptiles agree in one general plan, more specialized than that of Amphibia, and this can be said of the Birds and Mammals (Fig. 348). A review of the chapter on Comparative Anatomy compels the conclusion that the facts described there are without meaning if not explained by evolution.

FIG. 348.—KARL GEGENBAUR, 1826–1903. COMPARATIVE ANATOMIST.

5. *Embryology* furnishes plenty of evidence that is significant if viewed from the standpoint of evolution. Attention has already been directed to the *recapitulation theory*, according to which the development of the individual shows evidences that parallel the history of its kind. Ontogeny, it is claimed, recapitulates phylogeny. In spite of the fact that some enthusiasts like Haeckel (Fig. 349) applied this so-called law too widely, yet on the whole, the facts of embryology harmonize with those of Comparative Anatomy and Palaeontology, indicating organic evolution as the most plausible explanation of embryological facts. In interpreting development in the light of evolution, special structures and stages introduced because of the special conditions of development must be distinguished from primitive or phylogenetic structures which alone are of significance in support of the evolution doctrine. Characters which have had a long history are said to be *palingenetic*, while characters that have been later introduced to meet new contingencies of embryology are *coenogenetic*. The embryological evidence indicating the development of such forms as Reptiles and Birds from lower forms, special embryonic structures

such as yolk sac, allantois and amnion would be regarded as Coenogenetic characters. These appear as a consequence of presence of yolk and shell and the new development connected with them, while gill slits in reptile and bird embryos persist from an ancestral state and would, therefore, be palingenetic. Characters which are quite permanent in lower forms reappear for a short time in higher forms, and in the order to be expected of such a recapitulation theory.

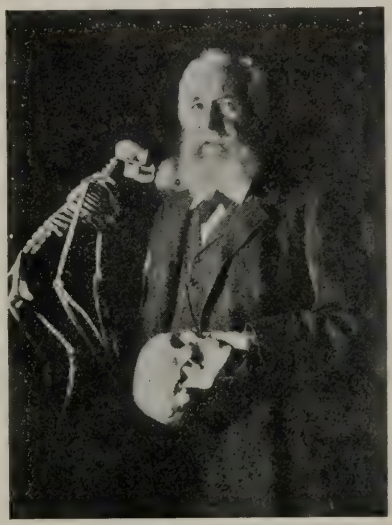

Fig. 349.—Ernst Haeckel, 1834–1919. Comparative anatomist and evolutionist.

The fertilized egg is protozoan-like for a short period, then it divides in a regular manner resulting in stages resembling certain colonial protozoa, and next a gastrula stage, beyond which plan the coelenterates do not develop. A third layer of mesoderm appears in addition to the ectoderm and endoderm. This third layer soon divides in one way or another to form a body cavity. Organs are gradually developed in much the same manner. The fundamental method and kind of development is surprisingly similar in all Vertebrates. In the embryology of a higher mammal some structures are more primitive than others and these are alike in all forms. The eye is an illustration of this. A Mammal develops gill slits like a fish, and these gills have temporary skeletal supports, arteries and veins and heart. Even the circulatory system is fish-like for a short time. The development of the ear at one stage is like that of a fish. Later one gill slit opening into the mouth is retained and becomes the eustachian tube of the air breather. Again the history of the placenta shows

evidences of modifications of the more ancient amnion and allantois. The development of the single uterus of Primates shows that it begins as two distinct oviducts as in lower forms. The adults of certain whales have no hair, no teeth, and no posterior limbs. Dissection reveals mere remnants of bones in the position of the hind limbs. In the embryo, however, the posterior limbs are formed, only to atrophy later. These embryos also develop a thick coat of coarse hair which atrophies; the embryos develop many teeth which are later absorbed. In the adult Ruminants such as oxen, sheep, and goats, there is no collar bone, but this forms in the embryo and is later absorbed.

Embryos of certain birds form teeth which are transitory. Birds in their development show many reptilian characters that later develop into bird-like structures, or remain more or less reptilian-like or disappear. There is no evidence that any of these rudimentary or transitory features have any use. The plausible view is that they are inheritances from animals in which they were used. Embryology has shown the relation of such forms as tunicates and amphioxus to Vertebrates, that the horseshoe crab, Limulus, is an Arachnid and not a Crustacean, and that certain parasites without appendages, muscles, nervous system, sense organs or digestive apparatus are degenerate descendants of higher and more complicated forms.

6. *Blood Tests.*—It has long been known that the blood of one species of Mammal is different from that of other species.

In 1904, Nuttall of Cambridge University, England, published a remarkable book entitled "Blood Immunity and Blood Relationship." This volume records results of thousands of experiments which constitute a physiological evidence for evolution.

Before presenting any results it is necessary to understand the methods used. A quantity of fresh human blood is taken and allowed to clot. A clear yellowish serum freed from corpuscles and coagulating ferments and products is obtained. Very small quantities of this serum (1 cc. to 2 cc.) are injected at intervals (two days for example) into the veins (circulation) of a rabbit. The bodily organization

of the rabbit reacts to the introduction of this foreign substance. An anti-body (antagonistic substance) is formed in the blood of the rabbit to counteract the toxic-like human serum. The injection of a large quantity of human serum all at one time would have killed the rabbit. The anti-human-serum-body formed in the rabbit is roughly comparable to the anti-toxin produced in horse blood when diphtheria toxin is intravenously injected into the horse. This periodic treatment of the rabbit is continued for some days then is discontinued. A waiting period of a few days follows. Blood is now obtained from the rabbit and from this a clear *rabbit serum.* If a drop of human serum is now added to the above a white precipitate develops which is an index of the neutralizing effect of the modified rabbit serum on the toxic human serum. The method can be used for other purposes. For example, if a few drops of a clear, saline extract of an old human bloodstain are added to such rabbit serum, a white precipitate is also formed. Although the bloodstain may be many weeks old, a positive result is obtained. If this immunized rabbit serum is tested with blood serum or bloodstain extract from other animals such as chicken, dog, cat, or cow, no precipitate is formed.

This is the most delicate and certain test for human blood known and is, therefore, made use of in criminal cases in the investigation of suspected bloodstains. It is known as the *precipitin test.* The rabbit can be immunized, however, against the blood of any animal. If cat serum is repeatedly injected, the rabbit serum will give a precipitin reaction to cat blood. Nuttall and his co-workers employed this method to investigate blood relationship among animals. They not only immunized rabbits to blood of animals of as many different orders or families as they could secure, but they also secured bloodstains from a great variety of animals all over the world.

Finding that a hunting expedition was starting for Africa, these investigators provided it with material for obtaining and preserving specimens of blood from all the animals captured. If a tiger was killed, the hunter soaked a small

sheet of filter paper in the tiger's blood. The stained paper was pinned up to dry. It was then placed in an oiled-paper envelope. The necessary identifying data were made, and after a quantity of this material had been obtained, it was sent to England to be used in these tests. The general conclusion was that blood of widely differing groups is similar, but that differences occur which correspond to other observable differences such as those of bodily structure. As the authors state "a common property has persisted in the bloods of certain groups of animals throughout the ages which have elapsed during their evolution from a common ancestor, and this in spite of differences of food and habits of life."

What results justify such a conclusion? The following examples serve to indicate the general nature of the evidence. A rather close relationship between man and apes is indicated, the precipitate with ape blood being more like that of human blood than is given with monkey blood. All Carnivores show a similar reaction to anti-carnivore sera. Closely related Carnivores give a better precipitate than more distantly related forms. If anti-cat serum is used, a precipitate is obtained with serum from a tiger or lynx, but a less distinctive precipitate with the serum of the dog or wolf. Anti-deer serum gives good precipitates with serum from antelopes, goats, sheep and oxen. Anti-whale serum gives best precipitates only with whale blood. Anti-lizard serum gives best reactions with lizard sera, but very good with snakes also. Anti-turtle serum gives best results with blood of turtles and crocodiles, and a fair precipitate with blood of birds. Blood of the horseshoe crab gives reactions with blood of spiders and scorpions and not with marine Crustacea. In all these cases the conclusions are similar to those obtained from a study of Comparative Anatomy, Embryology, and Palaeontology.

In addition to the facts of Comparative Anatomy, Embryology, Palaeontology, Classification, Geographical Distribution and Blood tests, certain observations made in connection with experiments in Genetics point toward this same general conclusion of organic evolution. This evi-

dence is involved, however, in the study of the possible causes of evolution and will be presented in the course of that discussion.

The Causes of Organic Evolution.—As stated above, many lines of evidence indicate that the organic world has come to be what it is by a process of evolution. The idea has somehow spread in recent years that biologists no longer believe in evolution and that it is a discarded theory. This is not the case. The reason for this misunderstanding can be explained. Probably the greatest contribution to the establishment of this theory was made by Charles Darwin (Fig. 350) Darwin not only made the masterly presentation of facts which have led scientific men to accept this theory, but in addition, he presented a possible *explanation of the causes of evolution.* His particular explanation of the factors which cause evolution is known as *Darwinism.* It will be defined presently. It is Darwinism that has been attacked by scientists and not evolution. It should be particularly noted, however, that the chief reason for everlasting fame for Darwin is that he so marshaled the facts in support of evolution that the theory was accepted by the scientific men of his day and is still accepted by scientific men. He is secondarily noted for Darwinism, his particular explanation of how evolution takes place. And not all scientific men regard this explanation as being as all-inclusive as Darwin maintained.

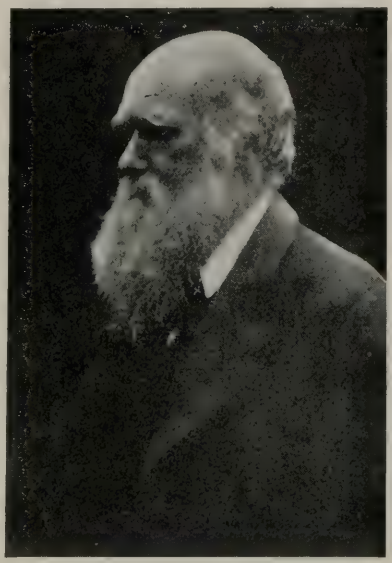

Fig. 350.—Charles Darwin, 1809–1882.

I. *Lamarck's Theory.*—Although there are indications

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that the idea of organic evolution was present in the minds of ancient Greek scholars such as Aristotle, the first serious attempt to explain its causes was made by Lamarck in his "Philosophical Zoology" published in 1809. Linnaeus, in the middle of the preceding century, had for the first time invented a good method for classifying animals and plants. He had evolved the idea of species or specialized kinds of organisms. He held that they were invariable and constant, that at the creation of the earth, one pair of each kind was created, that all species to-day are direct descendants of these, that there are just as many species to-day as were created at the beginning, and that there are no new species.

Lamarck had studied and classified a host of plants and animals and was an accomplished taxonomist. He could not accept the view of Linnaeus as to the fixity of species, and he suggested in its place the theory of evolution. He maintained, what is often lost sight of, that species do not exist in nature, but that the organic world is a vast assemblage of individuals that differ more or less from each other, and that there are all sorts of gradations present. He held truly that species are mere arbitrary human conceptions set up for convenience of classification, that transformations in animals have taken place, and that some of these are so considerable as to cause scholars to designate them as different or new species. He was one of the first to suggest the picture of a tree to elucidate the relations of various kinds of forms. He believed that favorable conditions such as those of soil, food and temperature accompanying changes in the environment would produce changes in plants directly and in animals indirectly; that new physical needs brought about by changes in the environment would call forth bodily changes. Land birds—to illustrate—compelled to take up an aquatic life would develop characters enabling them to swim or wade. He believed that competition in nature brought about changes, that larger forms would try to destroy smaller, and this would produce changes in each, that in-breeding of a race tended to preserve the peculiarities of that race, but that cross-breeding

would obliterate the peculiarities of each race involved, also that isolation tended to keep races distinct.

The two great laws of Lamarck are these: (1) *The Law of Use and Disuse.* Frequent and sustained use of an organ strengthens, develops and enlarges it; constant disuse gradually weakens it, decreases its usefulness, and finally causes it to disappear. (2) *The Law of Inheritance of Acquired Characters.* Everything that nature has caused individuals to acquire or lose by the long effect of external conditions, and so by predominant use of an organ or its lack of use, it *preserves by heredity,* and passes on to new individuals which descend from it, provided that the changes are common to those which have given origin to new individuals.

It is evident that Lamarck attempted to explain the origin of variations by use and disuse, though he gave little evidence for his conclusions. Modifications are produced by changes in the environment and there is also some evidence that these may produce offspring differing from the parent type. But in all these cases it can as well be said that the modified conditions modify the germ cells directly, and if this is true, then it is not a case of acquired characters. The differences in the offspring are not due to changes in the body or somatoplasm of the parent. Most biologists to-day do not consider that characters acquired during the lifetime of parents are transmitted to their offspring. Bouvier, a botanist, took the shoots of a certain plant and set them out at a high altitude. They grew up remarkably different from the plant from which they had been taken. When such plants or their seeds are grown at lower altitudes they again resume the original form. Tower exposed Colorado potato beetles of both sexes to varying conditions of heat and moisture during the time when the egg cells were maturing. The offspring showed distinct modifications and these were hereditary as long as he continued to investigate the matter, which biologically speaking was but a moment of earth history. Furthermore, Tower explained the results as being due to the action of the external conditions directly on the germ cells. As stated before, there is a great body of evidence showing that

organisms can be changed by external modifications. There is no evidence at all that the resulting somatic changes are transmitted to the offspring.

II. *The Theory of Natural Selection.*—This was the theory of evolution developed by Charles Darwin in his "Origin of Species" in 1859. "I am fully convinced," he wrote, "that species are not immutable; but that those belonging to what are called the same genera are lineal descendants of some other and generally extinct species." "Furthermore I am convinced that natural selection has been the most important, but not the exclusive, means of modification."

To gain an idea of what is meant by evolution by *natural selection* the process is divided into five stages: (1) *Variation:* The general occurrence of variation is well known. It has already been discussed in the chapter dealing with heredity. Lamarck tried to explain the origin of variations. Darwin took them for granted. (2) *There is a natural tendency toward the over-production of plants and animals.* At times the great wealth of living forms is brought to our notice. Sometimes when the usual unfavorable conditions are not present, species reproduce in a riotous fashion, as has been shown by the introduction of the English sparrow and the gypsy moth into America and the rabbit into Australia. Darwin pointed out that elephants begin to breed at thirty years of age and a pair may have six offspring in a century. If all the descendants lived and reproduced this original pair would, in 750 years, have nineteen million descendants. Woodruff ran an experiment for five years on continuous reproduction by fission in a certain species of Paramoecium. It can be understood why he did not keep all the offspring, as he computed that the total mass of protoplasm would have been 10,000 times the volume of the earth.

Over-production leads to (3) a *struggle for existence.* This may be between individuals of the same kind,—thus newly-hatched lobsters are great cannibals. Young trees growing close together in the forest are rivals. Bachelor fur seals battle for supremacy, the nations of mankind wage

war. There is also a struggle between members of different species. Illustrations are the destruction of animals by man, destruction of men by animals. In India, in 1910, 22,478 persons were killed by poisonous snakes, and over 91,000 snakes were killed by human beings. The destruction of insects and worms by birds, the destruction of caterpillars by wasps, the destruction of plants by insects, the destruction of animals by bacteria, are other familiar illustrations.

Animals and plants are also, at times, in fierce encounter with the environment. Death is only too often the result. The destruction of Pompeii and the earthquake and fire in San Francisco, are recalled. Drought not only kills plants but also animals which die from thirst. Unexpected cold has its victims. These are extreme cases, but a great amount of less conspicuous warfare goes on unseen. As a result of this struggle, out of all that begin life, only (4) *the fittest survive.* Those variations which are best adapted survive, those not adapted perish. These three processes—(*a*) tendency toward over-production, (*b*) struggle for existence, and (*c*) survival of the fittest,—constitute what is known as *Natural Selection.* Natural selection is necessarily related to adaptations, and those that are best adapted crowd out the unadapted.

(5) Finally in any one generation *only those animals posessing favorable variations with survival value can reproduce.* Therefore by *heredity* those advantages secured by natural selection are maintained. A constant succession of selections and further adaptations, generation after generation, results in the origin of new species. Variations of no survival value would not be selected. Natural selection does not originate variations, it merely preserves those that are of benefit under the peculiar conditions of life. It is in no sense a conscious process, but merely mechanical, as automatic as gravity and chemical affinity. Changes in the conditions of life tend to increase variability. Natural selection operates on internal as well as external organs. It is active at every stage in development from birth to death. Some characters are of apparent survival value, as

for example, the teeth of a carnivore. Other characters may be of important survival value although there may be no evident index of it at the time. Those chosen by natural selection have no insurance against accidental destruction.

Darwin was aided in the development of the natural selection theory by a study of *artificial selection*, the process by which various kinds of domestic animals and plants have been produced. (Fig. 351.) In a sense it may be considered a sort of experimental test of just what selection can bring about. Domestic selection extends far back into human antiquity. Man produces races which are useful to him in one respect or another. Some of these characters would be detrimental in a state of nature. Artificial breeds are often not stable and they soon revert to a state of nature. In some cases as in plants, man is able to continue the kind only by successive grafting. The navel orange is an example of this. In the case of many special animal breeds, close in-breeding of pure stock must be practised to maintain the breed. (Fig. 352.)

Darwin was familiar with 150 varieties of domestic pigeons all descended from the wild Rock Pigeon, *Columba livia*. Some of these domestic breeds date back before the year 1600. In a generation or two of interbreeding of mixed varieties, the offspring resemble the original rock pigeon.

Artificial selection resembles natural selection. The breeder begins with variations, there is a selection by him of these, and he breeds (heredity) those selected. Sometimes the selection is general, that is, the breeder eliminates the generally unfit. The result is a general improvement, but does not lead to production of any particular kinds. The breeder may work to secure an all-round, good animal, of large size, tame, fat, and fertile. New features may come to his notice and he selects, for mating, pairs that possess this new feature. He may specialize on one character alone, as greater milk production, more meat, more wool, or no horns. In the next place he hybridizes, or crosses, two related forms, as was the case of the domestic dog which is supposed to have been the result of the crossing of the wolf

FIG. 351.—VARIETIES OF DOMESTIC FOWLS.

In the center is the jungle fowl from India from which all domestic breeds have been produced by artificial selection and breeding. (Amer. Mus. Nat. Hist.)

FIG. 352.—VARIETIES OF DOMESTIC PIGEONS.

The wild rock pigeon is in the center. From this ancestral form domestic breeds have been produced. (Amer. Mus. Nat. Hist.)

and the jackal. The progeny will tend to vary. And this gives opportunity for further selection. The work of Luther Burbank in this field is unsurpassed. In cross-breeding, wider crosses can be made with plants than with animals. In animals, crosses of varieties alone are successful and these may not be fertile. The progeny of the male ass with the female horse is the mule, which is sterile. Its small hoofs, scanty mane, tail and voice appear to be paternal in origin. Its greater size, strength and form come from the mother. The mule is said to be more intelligent than the ass or horse. Cross a male horse with a female ass and the result is a hinny, smaller than a mule but more horse-like. The cross of the male California walnut with a female wild black walnut is a rapid-growing tree with no nuts. Reverse the cross and the result is a tree with larger and better nuts. Speedy race horses have been produced by artificial selection. A speedy horse must have light, slender legs. But there must go with this a certain size and muscular bulk. All increases in speed increase the strains to which the slender legs are subjected, in order to support a great weight in motion. Any further considerable increase in speed of race horses is not expected, for the limit has practically been reached.

Something similar to this is indicated by the nature of *heredity in pure lines*. Prof. Johannsen, a Danish botanist, was interested in seeing how far Galton's Law of Filial Regression would work. He thought it might serve as an instrument of continued racial betterment. He planned to select consciously the most exceptional offspring for parents in each generation with the hope of producing a permanent, non-regressive, exceptional stock. He worked with the self-fertilizing bean, *Phaseolus*. He chose nineteen beans of differing size and planted them. He thought that the progeny of the largest would be all large and those of the small bean, small, and so on for all nineteen. As a matter of fact, he found different sizes among the progeny of each. The largest of the smallest were not the largest beans harvested, but larger than he expected. He finally discovered in this variety of bean a number of pure lines

or races and each pure line had a mode of its own and its own variation about the mode. If he planted a seed from any pure line, the variation in size of its progeny was the variation of that pure line. If one selected beans of the largest pure line in the hope of securing still larger beans, his hope would be in vain. However, one could secure *large* beans, if only the largest pure line were kept pure. The conclusion is that selection within a pure line has no effect in modifying the size of beans. The germ cells of plants of any one pure line have the same genes and selection alone cannot modify these. Johannsen, in separating beans into different size groups in the beginning, was dealing with somatic characters. Phenotypes are merely those that have similar somatic characters. Genotypes are those with the same germinal composition. One might select seed of the same size that would be somatically or phenotypically similar, but might be genotypically different and this would be revealed in the variations in the progeny.

Jennings found similar results after he had ascertained pure lines in Paramoecium. Tower after twelve generations of selection in Potato beetles attempted to establish a dark variety, but without success.

Without giving any further criticisms of the theory of natural selection at this time, it is evident that the study of pure lines shows how inadequately natural selection serves as a complete explanation of the origin of new species.

III. *Isolation.*—One of the difficult things to understand concerning natural selection is why new advantages secured by natural selection, are not lost in breeding with individuals of an older, simpler sort. It has been argued by a number of workers that *isolation* prevents this. Isolation is a sort of selection which possibly segregates pure lines and permits inbreeding only among them. Gulick and Crampton have shown certain valleys running back from the shore in certain South Sea Islands to be populated by different types of snails, which are fundamentally related. Isolation preserves types once they are formed. Soil peculiarities, heat, moisture are also examples of possible agents of isolation.

IV. *Orthogenesis.*—Some biologists do not believe that variations are fortuitous. These investigators believe that variations occur in determined directions, leading to evolution along particular lines. This is due, they say, to the internal organization of that kind of animal or plant, which begins and continues to evolve toward a fixed end. During the process, the external forces are secondary. It is the internal organization that is primary. External influences, climate and food, however, may determine to some extent this internal organization. If this line of evolution produces something of advantage or disadvantage to the species then natural selection steps in. Evolution may take place according to the orthogenetic plan, but it is therefore not a cause of evolution, because it offers no explanation of the origin of the supposed fixed variation.

One of the reasons advanced against the acceptance of the theory of natural selection is that the small first stages in the development of vitally important adaptive structures would have no selective value. The orthogeneticist claims that structures appear that are adaptive from the beginning. Osborn is convinced that mammalian teeth indicate this. In many orders of mammals, the teeth develop with a few similar cusps. These cusps arise independently, gradually, along definite lines, until they are adapted for their work. He believes that selection had nothing to do with this, but that it was due to a predetermined, underlying, germinal constitution. The material obtained for the study of the history of the horse indicates evolution in a straight line. This also is a case of orthogenesis. Then again, there are examples of evolution in a straight line continuing to a point where the structures are over-developed and are a positive menace to the animal in the struggle for existence. Illustrations are those of the great tusks of the wild boar; the antlers of the so-called "Irish Elk" which, at the time of its extinction, bore antlers thought to have been heavier than the rest of the body; the enormous bulk of some of the dinosaurs; the great horns and skull, frills of the rhinoceros-like Dinosaurs; and the terrible canine teeth of the saber-toothed

tiger, Smilodon. Such over-developments might have been "fitted" for the conditions then prevailing. When conditions of life changed, such highly specialized structures were not adapted and caused the extinction of these creatures. Natural selection may thus be the deciding factor in determining the permanency of orthogenetic variations.

V. *Mutation.*—Darwin did not try to explain the origin of variations, nor did Lamarck explain their origin at all satisfactorily. The mutationists, founded by Hugo De Vries of Holland (Fig. 353), believe that new species arise suddenly and that offspring appear with well differentiated variations, not possessed by the parents or the parental line. The mutationist does not believe that natural selection really starts species. Natural selection controls the persistence of this and that mutation. The variations emphasized by Darwin were small and fluctuating. He believed in a gradual quantitative increase in these, generation after generation, by natural selection. But the mutationist claims that such variations are of no evolutionary significance, they get nowhere, they are like the endless rise and fall of the tide. Darwin described such sudden distinct, discontinuous variations, but assigned no importance to them. He even described what is now thought to have been a mutation.

FIG. 353.—HUGO DE VRIES. MUTATIONIST.

In 1791, in Massachusetts there appeared in a flock of a certain breed of sheep a short-legged ram which was of a distinctively different type. This ram bred to females of the breed, from which he so suddenly appeared, produced offspring that were like him. Thus a new breed, the Ancon breed of sheep, was begun. Due to the short legs, these sheep could not jump fences. The breed was discontinued when the Merino with a better grade of wool was introduced. Bateson in England, in 1894, in

" Materials for the Study of Variation," called attention to 886 cases of discontinuous variations. Discontinuous variations were called " sports " by Darwin, such distinctly different characters as a four-horned sheep or an eight-fingered man or a one-toed pig. But all discontinuous variations are not alone differences in numbers of parts. They may be differences along any line, as color, form and size.

The classic case of mutations is that described by Hugo De Vries of Amsterdam, in his book " Species and Varieties," published in 1904. This book gives an account of years of hard work. De Vries is the father of the mutation idea. The rediscovery of Mendel's principles by De Vries, about 1900, during the period of his investigations, influenced him in his conclusion that evolution did not take place by the gradual accumulation of slight, fluctuating variations by natural selection, as Darwin had maintained, but by the sudden appearance of a *full-fledged elementary species*. His studies were made on a primrose of the generic name Oenothera. A certain species, *Oenothera lamarckiana* was indigenous to America. It was taken to London about 1860 as a garden plant and was introduced in other places in Europe. It spread outside of gardens and De Vries found it growing wild in a potato patch a few miles from Amsterdam in 1886. He observed that it presented considerable variability. *Oenothera lamarckiana* is a large bushy plant over four feet high with large bright yellow flowers which open toward evening, hence the name Evening Primrose. Among them he observed different and distinct types. Wishing to study the matter he experimented further with them in the Botanical Gardens at Amsterdam. He transplanted some of the wild plants or gathered the seed for planting in his garden, and sowed the seeds which developed on the transplanted plants. In seven years he had grown and studied 54,343 plants, 837 of these were new types, or Mutants. He writes, " These various methods have led to the discovery of over a dozen new types never previously observed or described."

Among the wild Oenotheras he found two different types which he called *O. brevistylis*, because the style of the pistil was short, and *O. laevifolia*, because it had smooth leaves. He regarded these as *mutants*. In his gardens in those years of cultivation, he claims to have found seven other new elementary species all originating from self-fertilized seeds of *O. lamarckiana*. A systematist would regard them as distinct species. It has been suggested that possibly the results of natural hybridization of two or more wild species produced so-called new species which are merely different types of hybrids. Davis has crossed two wild American species and has produced a hybrid resembling *O. lamarckiana*, and this produces forms resembling the mutants of De Vries.

De Vries's work has been repeated and his conclusions confirmed. In 1899, a hornless Hereford appeared in Kansas. From this animal has arisen the hornless breed of Hereford cattle. Tailless cats, dogs, and poultry are probably mutants, so also are hairless dogs, horses, cattle and mice.

T. H. Morgan and his co-workers, in their most careful investigation with the rapid-breeding fruit fly, Drosophila, have found hundreds of suddenly appearing new characters which they call *mutations*. Most of the mutants have a "lethal" characteristic and the animals showing these particular mutations die. Most of the experimentally produced mutations in fruit flies differ from each other in only one or two features while ordinary wild species differ in many individual characters. And yet this is no real criticism, for if one new character could arise as a mutation there is no reason why many should not do so. Morgan has pointed out features wherein the mutation theory escapes the criticism of the Darwinian theory of natural selection.

As mutants appear fully formed, there are no initial stages to account for. Useless structures appearing as mutations may persist if they are not detrimental to the continuance of the species. Also mutants may be better fitted to live in a different environment than the parental forms. This might lead to isolation which would prevent

hybridization (and hence loss of the newly gained advantage) with the parental form. The mutant may differ "from the parent form in only a slight degree for each point, although all the points may be different." (De Vries). Moreover the characteristics acquired by mutation are inherited. This is the most important point necessary to explain evolution.

A certain amount of experimental work has thrown light on the origin of mutations. After obtaining a pure race of potato beetles (*Leptinotarsa decemlineata*), Tower subjected them to different conditions of temperature and humidity. The few offspring showed decidedly different characters and they bred true to these new characters, and Tower claimed them to be mutants. Gager exposed ovules of plants to radium rays which apparently changed the germ cells, for the plants were stunted and abnormal. Some of these continued for several generations. MacDougal injected cane sugar, and zinc salts into the ovules of different plants and forms varying distinctly from the parental type developed. These also bred true for the few years that he continued the experiments. An attempt has been made to correlate the origin of mutations with the number and size of chromosomes. The typical number of chromosomes in *O. lamarckiana* is 14 but Gates has found 15, 20, 21, 22, 23, 27, 28, 29, 30, in some. In the fruit fly, Drosophila, Metz has found variations in the number of chromosomes even to a doubling of the number, but the quantity of chromatin remains the same.

The discovery of *pure lines* indicates that the best that selection can do is to isolate pure lines. Selection cannot change genes. Genes, factors or determiners of heredity (i.e., chromatin), have been shown to be possessed of great stability. Morgan cites evidence indicating that factors or genes are not variable. It is true that the production of the extremely valuable domestic plants and animals has involved selection. But it is now believed that other factors have been involved, which were unknown to the producers of these useful breeds. In many cases, the breeder has unconsciously been selecting a "pure

line," a " genotype." Or again mutations have probably been chosen. Ears of corn are now grown which are larger and better than any that appear in a state of nature. Often mutations can be artificially preserved that would disappear in a state of nature. Luther Burbank makes all sorts of new combinations by hybridization. He destroys all progeny but the one that suits him even though the others run into the thousands, and, as a rule, continues his new form by such methods as grafting. According to Morgan it is possible to form apparently new characters by combinations in hybridization. These can be preserved by following out the procedure indicated by Mendelian heredity as at present understood. If indifferent mutations arise, their future continuance is a matter of chance. If injurious mutations arise they will disappear by natural selection. If beneficial mutations arise they will tend to be preserved by natural selection. There is no evidence that natural selection determines the formation of favorable variations.

Morgan says that " Evolution has taken place by the incorporation into the race of those mutations that are beneficial to the life and reproduction of the organism." Lull summarizes the controversy concerning the origin of variations. He does not mention mutations, for they would be included as a kind of variation. The three explanations are:

I. An inherent tendency in the germ plasm to vary. This is begging the question. Moreover, the results of Mendelian work in heredity negative it.

II. Variations are due to the indirect influence of the changing environment on individuals which produce by germ cells. The same studies in heredity, as shown above, indicate the falsity of this view. If there is any change, it is due to the direct effect of environmental conditions on the germ cells.

III. Sexual reproduction involving new combinations when parental and maternal chromosomes fuse will produce offspring different from either. This is the amphimixis of biparental marriage. Against this idea is brought forward the objection that it would not explain variation in asexual

forms such as those of Protozoa. However, sexual reproduction appears very early in the Protozoa.

Parthenogenetic forms such as bee drones and aphids also vary as shown by Kellogg, but here it might be answered that sexual phases occur interspersed with asexual generations in the case of these partheogenetic forms.

What other explanation can be given for sex? Conklin says: " The production of unique individuals seems to be the chief purpose and result of sexual reproduction." He further recalls the fact that each human germ cell before fertilization contains 24 (or 23) chromosomes. Evidence has been given showing that the chromosomes are composed of genes, determiners of somatic characteristics, and also that the chromosomes differ in hereditary possibilities. Suppose the chromosomes of the egg differed from one another in one character each. The possible combinations of only these twenty-four characters would be 16,777,036. There would also be as many types of sperm. The possible combinations of these in sexual reproduction would be about 300,000 billions. It is possible that mutations arise in the ample combinations of amphimixis.

This implies, however, that the lowest protozoa and protophyta contained all the factors out of which by a successive sorting out, the present world of plants and animals has been evolved. Bateson has suggested such a fanciful proposition. Somehow one cannot sidetrack the ever-intrusive thought that the constant effect of environmental conditions has had a great deal to do with evolution; but not in the simple way suggested by Lamarck. In a sense, water at one time was a mutation, so was carbon dioxide and urea and ammonia, and other compounds. These combinations are so relatively simple that the physical scientist can experimentally reproduce the mutation. When enough is known about the physics and chemistry of somatoplasm and germ plasm to manufacture mutations that already exist in nature, then something will be really known about the origin of mutations or variations that will be of evolutionary value. This may not be so far distant. Morgan says: " The causes of mutations that give rise to new characters we do not

know, although we have no reason for supposing that they are due to other than natural causes." Bateson, however, in speaking of the larger question of the causes of evolution pessimistically says: "The many converging lines of evidence point so clearly to the central fact of the origin of forms of life by an evolutionary process that we are compelled to accept this deduction, but as to almost all the essential features, whether of cause or mode, by which specific diversity has become what we perceive it to be, we have to confess an ignorance nearly total."

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CHAPTER XXIX

THE BIOLOGY OF MAN

There are many references in the preceding pages to organisms which affect man. · However, since man himself is a living organism, he also is a proper object for biological investigation. As a part of the great living world he may occupy a lofty seat in dominion over inanimate nature, over plants and over the lower animals, but he is nevertheless fiber of the living fabric of nature, and a product of ages of adaptation. From a taxonomic point of view, he is without any doubt a chordate, for a notochord, gill slits, and a hollow dorsal nerve cord appear during the course of his embryonic development, just as they do in the life of a fish, a frog, a lizard, a hen, and a cat. He has a jointed backbone and so is a Vertebrate; he has warm blood, hair and a diaphragm separating the body cavity into a thorax and an abdomen, and so is a Mammal.

Man is a placental Mammal, because in the development of the embryo there is no great quantity of yolk present, and the old reptilian allantois and amnion are arranged to develop into a placenta. He is a Primate, for he has prehensile limbs, his thumb is opposable, his digits have flat nails as a rule, he has a collar bone or clavicle, and his mammary glands are thoracic. Linnaeus proposed the word Primates to designate the first and highest group of animals. Although Primates such as the chimpanzee and gorilla have not been domesticated, as have the dog, elephant and horse, yet the relatively small amount of investigation so far given to the matter indicates that these Primates are the most intelligent of all animals below man. It is the further development of the brain, and everything that this signifies, that places civilized man far in advance of other Primates. Chemical analysis

of the body reveals the same chemical compounds, organic and inorganic, as are found in other animals, about the same amino-acids, and about the same elements.

Embryology.—A careful study of the *embryological development* of man begins with an egg cell, 0.25 mm. in diameter, a microscopic speck of protoplasm, a typical cell with a nucleus. After fertilization, cleavage stages appear, then a blastula stage is developed followed by a gastrula stage with ectoderm and endoderm and later mesoderm. A mouth forms by invagination. Other organs which develop are the notochord, the nerve cord, the gill slits, the fish-like heart, the cartilaginous skeleton of the shark, the allantois and amnion of reptile and bird. One can see the heart change from a two-chambered, to a three-chambered, and then to a four-chambered organ with right and left sides. One can see the lungs, liver, pancreas, pronephros, mesonephros, testis, ovary, Wolffian duct, Müllerian duct (oviduct) form as in other Vertebrates. In certain early stages it is difficult to decide to what class of Mammals this embryo belongs, then mammalian characteristics appear and later primate characteristics. So far as hundreds of embryological observations go, man is plainly a Primate, a Mammal and Vertebrate.

Histology.—*Histological investigation* shows his skeletal muscle to be made up of muscle fiber units as in other Vertebrates, surprisingly like that of the Mammals and especially the Primates. Histological examination of the smooth muscle of the intestine shows that it is composed of smooth muscle cells as in the intestines of other Vertebrates and more especially Mammals. Similar epithelial cells are found in corresponding locations. Connective tissues such as bone, cartilage, fat, are similar, also the most specialized of all tissues, neurones, are similar. No different types of neurones are found in man than are found in other Mammals. Detailed histological studies of the various organs reveal the fact that liver, pancreas, kidney, testis and lung are all built on the same general plan as the lower Mammals. Microscopic resemblance is borne out by the searching powers of the microscope. *Physiological and*

pathological processes are also similar. When, by experiment, causes of disease in lower animals are discovered and such diseases prevented or cured, this same knowledge can be applied to the same diseases in man and with the same result.

Comparative Anatomy.—Galen (2d century, A.D.), the most able anatomist of antiquity, taught for a while at Rome. He was not permitted to dissect human bodies, and was compelled to use bodies of lower animals in his demonstrations. Despite this, his errors were mostly in details, for in general outline, the anatomy of a dog or cat serves fairly well to illustrate human anatomy. When a monkey or, better still, a chimpanzee is available the resemblance is still more striking. When compared, the skeletons of a man, chimpanzee, gorilla, cat, dog, deer, and horse, part by part, and bone by bone, reveal differences, but what attracts attention most are the similarities in all these Mammals. Correlated with different forms of locomotion one notes differences in shoulder girdles and in the feet (especially the fingers), of all the above examples. Correlated with differences in food one finds differences in skull structure, teeth, etc. Correlated with differences in intelligence one finds differences in cranial capacities and brains. Due to differences of food one finds specialized stomachs in Herbivora, as compared with Carnivora or with Omnivora (man). But the general structure of the voice-box, larynx, trachea and lungs, oesophagus, stomach, intestine, heart, arteries, veins and capillaries, liver, gall bladder, bile duct, adrenal gland, general anatomy of the brain, spinal cord, cranial and spinal nerves, sympathetic nervous system, demonstrates without any questioning a similar groundwork behind the differences. When man is examined from any morphological, physiological, histological, embryological or chemical standpoint, the only rational conclusion is that the same agency that fashioned fish, frog, lizard, bird or other Mammal also fashioned man. The man-like or Anthropoid apes, of all other animals, most closely resemble man. Man did not evolve from these apes, but both had a common ancestor.

The species, *Homo Sapiens*, family Hominidae, shows in many details of gross and detailed structure close similarities with the Simiidae. Terrestrial life in the open, erect posture, and greater development of the brain have produced differences. Bipedal locomotion has changed the curvature of the spine, lengthened the legs, modified the opposable character of the great toe, freed the arms for a multiplicity of motions, increased the use of the thumb, and made the hand a great instrument of use for attack and defense and for gathering and preparing food.

The human body exhibits many primitive characteristics. The radius and ulna are well developed, and many of the wrist bones are distinct. The fibula of the leg is quite large, and the foot is plantigrade. There are still five digits, and the number of phalanges is the same as the primitive number. The shoulder girdle retains the clavicle. The atlas supporting the skull is primitive. The teeth are simple and the premolars are simpler than the molars. The stomach is far simpler than that of the ruminants, and the vermiform appendix is far less specialized than in the Rodents. In many respects man is generalized in structure, but he also exhibits specialization, such as four curvatures of the spine at maturity and the basin-shaped pelvis aiding in the support of the viscera. The pelvis of Anthropoid apes is flat as is that of human embryos. The forelimbs are short. In the foot, the great toe is very rarely opposable, the shock-preventing arch has developed so that the axis of the foot runs along the inner side through the great toe which is largest, the others having become smaller. The fusion of the two end phalanges of the fifth toe, in a number of cases, is interpreted as an indication of the progressive diminution of the outer toes and increase of the great toe. The hair scattered over the body usually disappears, possibly as a result of use of clothing, and the skin is thus more sensitive. Skin pigment has disappeared in some races. There are thirty-two teeth as in the Simiidae, but they are relatively smaller, especially the canines. Tooth reduction is apparently taking place, as is evidenced by frequent lack of the second incisors and the third molars.

The face is shorter and the facial angle tends to approach a right angle. The facial angle is obtained by drawing a line from the lower margin of the nasal aperture to the ear opening and another line from the forehead to the upper jaw. In the Anthropoid apes this is an acute angle. In size the human brain is, on the whole, relatively larger than that of any other Vertebrate. Especially prominent is the large size of the cerebrum in proportion to the other parts (Fig. 354). The cerebellum though much smaller than the cerebral hemispheres is relatively large also. The cerebrum covers

FIG. 354.—COMPARISON BETWEEN THE BRAIN CASE OF APE AND MAN.

(Amer. Mus. Nat. Hist.)

the cerebellum above and the cortex of the cerebrum is increased in area by a complicated system of convolutions and fissures. Especially well developed are the frontal lobes, supposed to be the physical seat of the higher intellectual powers.

Articulate speech is a special distinguishing characteristic also. There is no doubt but that this has its physical basis in the greater development of certain regions in the brain. Interchange of experiences between individuals is thus possible. Two brains are better than one, which leads to the formation of generalizations, abstract thought, and hence reason. It is impossible in this synopsis to develop further the very evident relation between development of

language and civilization. There is no question but that a wide gulf separates man from the Anthropoids and hence from the rest of animal creation. There is no doubt nevertheless that underneath that gulf extends the connecting ocean floor of fundamental resemblances.

Rudimentary Characteristics.—Most persons have the following characteristics: (1) hair which runs from the shoulder toward the elbow and from the wrist to the elbow. This is also found in Anthropoid apes. Hair is oily and thus placed would shed rain from an animal crouching in a tree with his arms over his head, as is often the posture of the orang. (2) The vermiform appendix is short in man and in the apes. It is large in the embryo but growth ceases and it becomes relatively small. It is smaller in some persons than in others. Apparently the body functions perfectly without it. In certain herbivorous animals, such as the rabbit, it is large and functional. (3) Dogs and other animals have well-developed muscles for erecting the ears and the hair. They are still present, but are small, and usually do not function in most persons. (4) In the inner corner of the eye is a little fold called the *Plica semilunaris*. This is all that is left of the third eyelid or nictitating membrane of the eye of some Mammals and Birds. (5) The pineal body rising from the dorsal surface of the diencephalon is a mere remnant in man. In certain Reptiles it is connected with a median eyelike structure in the middle of the head. (6) In most Mammals the incisor teeth in the upper jaw are borne on a separate bone called the premaxillary. There usually is no sign of such a separate bone in either men or the chimpanzee, but separate premaxillary bones in man have been found. (7) The dorsal and front part of the brain in most Mammals is protected by a pair of frontal bones. In man this is single in the vast majority of cases. (8) In rare cases a gill slit remains at maturity. Some vestigial structures appear during development, only to disappear later. It has been stated that the first gill slit is normally retained as the Eustachian tube of the ear. Cases have been found in which more than one gill slit was developed into an ear

chamber, and extra external ears appeared. (9) The tail of the adult is reduced to a mere vestige. When it fails to discontinue development, human infants appear with tails. In embryos it is present, and has muscles formed to connect with it as in tailed forms. (10) Up to the sixth month of prenatal growth the body develops a coat of long black hair called the lanugo. This disappears before birth. Sometimes it persists, animal-like, in the adult. The embryos of hairless Mammals such as the elephant and whales also have the fœtal lanugo.

(11) It has been observed that newly-born babes have the remarkable power of supporting the weight of the body by clinging to some object like a stick. This power continues somewhat diminished for several weeks. It is interpreted as being a vestige from the old arboreal days of the race. Wiedersheim distinguishes 180 such vestiges, and pessimistically calls attention to the imperfections of the human body wrought by natural experiment during the ages. Almost any good oculist could give plans and specifications for a better all-round standard eye than man possesses. This is also true of other organs such as the ear, teeth, lungs, stomach, colon and heart. As one gazes on the works of ancient artists and sculptors one is led to conclude that the race of men must have been perfect in those days. They depicted strong-limbed, perfectly proportioned men, and women of beautiful form. Such conclusions are erroneous. Those great artists did not picture the average human form as it then existed, but they represented the perfect type as they wished to see it. In spite of the fact that modern science was not present to save for reproduction the weaklings, it is very probable that the lame, the halt and the blind then existed. Men as a rule have not been the perfect specimens indicated by Phidias or Raphael.

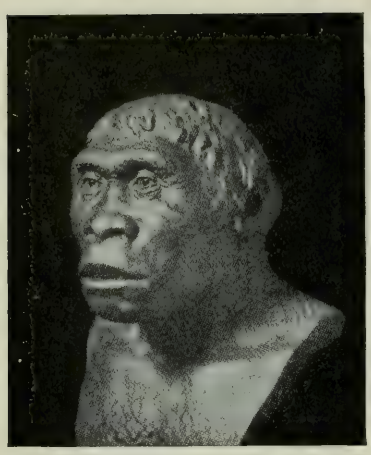
Palaeontology.—The science of Palaeontology with the evidences collected, indicate that Carnivora and Primates arose from an Insectivorous-like form, very early in Cenozoic time; that the Primates appeared in the early Eocene period in that portion of the world as far south of the north

pole as would now include Asia. Fossil Primates have been found in America and Europe during the Oligocene. They reappear in Europe in the Lower Miocene. They were compelled to migrate, due to the southerly progress of cold which killed the forests. Their continued presence in Southern Asia, Africa and South America, indicates evolution in these localities after this southward migration.

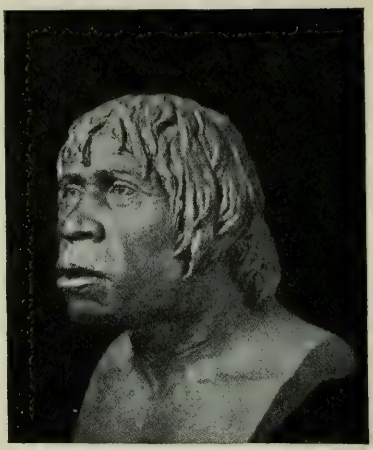
There are several reasons for the belief that the form, ancestral to man, changed from an arboreal habitat to a terrestrial one in Central Asia, somewhere between Miocene and early Pliocene time, and that the human type emerged during the Pliocene, hundreds of thousands of years ago. Change from an arboreal to a terrestrial life involved erect posture, which freed hands to execute thought plans. The necessity for finding food, developed the hunting habit. The use of clothing and of a great variety of food meant ability to range far and wide and the further development of social organizations for the mutual benefit of individuals.

Fossil remains of ancient man are very rare. What is regarded as the partial remains of a primitive man was found in Java in 1894. The skull cap, left femur and two upper molar teeth were recovered. Careful comparisons indicate that the animal was rather prehuman than ape-like. The skull capacity was two-thirds of the average human skull. The forehead was low and flat, with prominent supraorbital ridges. The brain was therefore small and the frontal lobes especially so. The teeth, though primitive, were more human than ape-like. The body height was probably nearly as great as that of living men. Fossil animals found with it, place it between Upper Pliocene and Lower Pleistocene. This is known as the Java ape-man or *Pithecanthropus erectus*. (Fig. 355.)

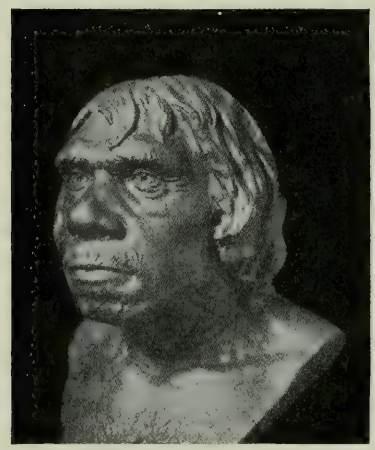
A mere fragment of what is regarded as the oldest European race, of which there is any evidence, was discovered seventy-nine feet below the surface in river sands near Heidelberg, Germany, in 1907. This fossil was a perfect lower jaw with teeth. It used to be said of Cuvier, the great French comparative anatomist and anti-evolutionist, that he could examine a single bone and identify the animal



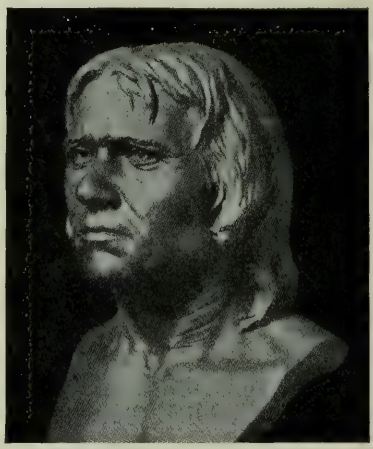
JAVA MAN
Pithecanthropus erectus.



PILTDOWN MAN
Eoanthropus dawsoni.



NEANDERTHAL MAN
Homo neandertalensis.



CRÔ-MAGNON MAN
Homo sapiens.

FIG. 355.—HEADS MODELED BY PROFESSOR J. H. MCGREGOR.

Based on his exhaustive studies of skulls of ancient human types. These types probably represent four divergent lines. From original models in the American Museum of Natural History. (Courtesy of Dr. McGregor.)

of which it had been a part. This Heidelberg Jaw has been studied most carefully by even greater experts than Cuvier, and it is regarded as belonging to a higher race than Pithecanthropus. From other fossil remains found with it, such as those of primitive elephants, horses, lions, it is believed to have existed about 375,000 years ago in the second interglacial age. There are also indications that these men selected and used particular shaped stones as tools in their daily occupations.

What is known as the Piltdown man was discovered in Sussex, England, in 1912. Portions of a brain case, a canine tooth and part of the lower jaw were found. The tooth and the jaw are thought to have belonged to a chimpanzee. The skull remnants indicate a high human type. The so-called Piltdown man is thought to have lived from 100,000 to 150,000 years ago. In 1856 a skeleton of a primitive man was found in a limestone cavern near Düsseldorf, Prussia. It was partly destroyed by its discoverers. Later similar specimens were found at Spy in Belgium, and in France. It is claimed that they evidence the existence of a primitive race known as the Neanderthal Men; short in height, strongly built, with prominent overhanging brows, retreating forehead, large and human-like brain, massive jaws, receding chin, large hands, thumb not greatly opposable, short lower leg. They were probably not erect and walked with a shuffling gait. This Neanderthal race lived in Europe from the third Interglacial stage 150,000 years ago, through the fourth glacial period. They were unprogressive, but had at least developed, well wrought flint tools and ornaments, which they buried with their dead.

In Wales and France skeletons of an ancient type were excavated years ago, but were not given close study. Five more skeletons similar in character were found in Cro-magnon France, in 1868. These remains have established the existence of the Cro-magnon race of men. It is described as having been a magnificent race—superior to many existing to-day. The men were over six feet in height, probably taller than the tallest living races. They had

large brains, high foreheads and a facial angle as high as modern men, wide short faces, prominent cheek bones, strong jaws, prominent chins, long legs and were, therefore, swiftly moving. Their burial customs indicate belief in immortality. They lived for a time contemporaneous with Neanderthal men, and appeared possibly 50,000 years ago. This race finally declined, leaving but few survivors. Some of these live in France to-day. On the walls of caves in France and in Spain Cro-magnon artists made drawings of themselves, of their tools, and of the animals of their day. Fortunately these drawings, preserved for thousands of years, have again come to the view of the descendants of other races of men, who migrated to Europe from Asia. The repopulation of Europe probably took place in the upper Paleolithic, 25,000 years ago.

There are many evidences of human antiquity. How did the ancestors of the American Indian reach this continent? It is unlikely that they could have crossed great sea-distances in the little boats known to ancient men. They may have wandered by way of Bering Strait. The discovery of ancient cities in South America which flourished long before the Christian era, indicate the relatively great antiquity of native Americans. The North American Red men, the Eskimos, the superbly physically perfect peoples of some of the South Sea Islands present other problems. No records exist that give information of their origin. This distribution to the uttermost parts of the habitable globe and subsequent establishment there in the absence of easy methods of transportation must have taken great periods of time. There are no evidences of great sudden environmental changes which would have brought this about. The production of different races must have taken a long time. Egyptian paintings, several thousand years old, indicate that certain races had even then been long established. The development of intelligence was slow also. Babylonian inscriptions, twice as old as the times of Abraham, indicate that civilized nations had existed thousands of years before. The paleontological evidence while meager, yet corroborates the other evidence.

Due to the development of the brain and the acquisition of intelligence, man with his relatively poor eyesight extends his vision by means of invention and can see microscopically and macroscopically infinitely more and better than any other animal. With his limited sense of hearing he can also hear further than any other animal. He can talk across oceans and around the world. Though heavy limbed, he can outrace the swiftest antelope; terrestrial in habit, he can explore the depths of the ocean like the whale and lacking wings, he can soar far and high, better than any bird. Due to recorded written language, he can repopulate the stony piles of ancient cities and reconstruct their streets, re-establish their commerce, and can view again, centuries later, their birth, their development and decline. He is the most highly adapted of all living things. He has wrenched secrets from Nature, and her forces are his servants. He knows Nature and he knows himself, a little.

But these accomplishments are not true of all men. Races of men exist on the globe to-day, as they have existed for ages, and are but little higher than other animals. Nor have *all* men who live in civilized communities accomplished great things. Many even now spend their lives in a mere existence but little above that of the animals. This is true not only of the financially poor, but more especially of those who have poor mental capacity. The lordship of man has been accomplished by those who were born unusually strong, courageous and daring; by the adventurous, and by those endowed with unusual intelligence. Progress has always depended upon leaders. Variation among men is a primary biological law, for they are certainly not created equal. One is born with one talent, one with ten, one with a thousand. The creative genius, moreover, is not inspired to accomplishment by expected fame or fortune, but rather because of an inborn urge for expression. It is probably due to a fortuitous combination of genes, rather than to postnatal circumstances.

Civilized man is possibly not as strong muscularly, nor as keen of sight or hearing, nor so adept with his hand, as his forefathers were. And this is due to the appearance of

his inventions which so marvelously complement or excel his foor faculties, and lead also to a certain amount of disuse. There is danger in this and it should not be forgotten that an overspecialization in a changing world has caused the extinction of more than the Dinosaurs.

Euthenics.—Euthenics means improvement of conditions—better water supply, better air, better habitations, better food, more wages, more rest and recreation. Medicine is changing from an art to a science, an achievement which is the result of biological investigations. Prevention of yellow fever, malaria, typhoid, diphtheria, smallpox and scarlet fever are instances of victories over disease organisms. The saving of man's domesticated plants and animals from destructive parasites is another sort of biological work, all in the general direction of human Euthenics. Agricultural science has developed largely by the same agency, namely, biology. In all of this work use has been made of physics and chemistry, which are fundamental to biology. Compare the England of to-day with the picture drawn by Mark Twain in " A Connecticut Yankee at King Arthur's Court " and note the differences that have taken place in a few hundred years. Mark Twain was not primarily interested in telling a funny story, when he visualized the state of English society in the days of King Arthur. It has been claimed that the saving of lives by improved euthenical conditions (and this includes not only the work of all philanthropies, but of all medical science) works to the detriment of the race and that the general effect is the survival of the unfit, the propagation of those who will become a burden and a menace to society.

One answer to this argument is that countries which stand highest in euthenical progress should be compared with countries where practically no attempt is made to improve conditions, but where natural selection is left comparatively free to eliminate the unfit. Compare, for example, the people of the British Isles with the natives of India; compare Americans in general with the great population of China. One cannot escape from the conclusion that euthenical progress is a sound policy and is

good biology. Oftentimes charity and philanthropy take a distressing situation and clear it up. As the result of a helping hand, helplessness disappears, and even productivity is brought about. Parents, poverty stricken through disease or other misfortune, die and leave children who, rescued by charity, grow up into able and valuable citizens. Death is often due to maladjustment of just one part of the living machine. The person involved may be of great potential value to society. Medical science corrects this abnormal condition. A lifetime of usefulness is the profit gained by society.

The public is constantly being informed of the discoveries of medical science. Information regarding the safeguarding of health is given, and there is no question but that, on the whole, men are disposed even from a selfish standpoint to profit by it. Society is the gainer, due to added years of usefulness. There is no question but that human disease is a great tax upon resources of society. It is a burden that rests upon the shoulders of the well. Moreover, such countries as England and America do carry such a burden, and also lead the world in accomplishments. Somehow, sadly deficient as it is, modern euthenical policy in civilized countries helps to conserve intelligence and prolong the period of productiveness. The effect of saving the weak often means that many of these weak are made strong enough to erect tier after tier of building blocks in the great edifice of a modern civilized society before death finally claims them. And once built, the gain remains an imperishable advance over what existed before. Where nature alone applies her ruthless laws the edifice is slow in building or is never built.

Moreover, what is a perfect organism? Is it not a body perfectly adapted? Is not medical science above all things taking a hand in this very matter, and aiding in adaptation? Is it not pointing out a thousand kinds of imperfect adaptations, and constantly correcting these? Is it not, after all, a case of intelligence stepping in and boldly wresting from nature the application of her laws by substituting a better law?

Eugenics.—What other program does the objector to the present-day euthenic policy suggest and why is this considered necessary? In the first place, the program urged is called Eugenics. The word literally means "*well born.*" It is more of a propaganda than a science. It is a position that an intelligent person must take after ascertaining the facts of human heredity or genetics. The investigation of human inheritance reveals the perpetuation of many distressing conditions in man. Not only are defects, abnormalities and weaknesses at times perpetuated in increasing numbers, but this unintelligent policy results in burdens that must be paid for by society at large.

The eugenist rightly claims that far more care and scientific common sense is employed in raising good vegetables and domestic animals, than men. For ages man has deliberately chosen the best for parents of his domestic animals, in his endeavor to produce a desired breed. He is only too careful of his pedigreed stock. But where human breeding is concerned, this has been allowed to take its course. The reason probably is that no man considered himself warranted in interfering in a matter of individual liberty, and it is certainly true that men have fought and died for that precious possession—human freedom. Murder was probably committed at one time with impunity and so was theft. But somehow these and a host of other manifestations of human freedom of action have been curbed as not being in the interests of men as a group. Undoubtedly the discoveries made in the study of human heredity will lead to a curbing of freedom in marriage. What facts indicate that this position is warranted? Certain common human defects have been proved to be dominant Mendelian characters, such as cataract, an opacity in the transparent part of the eye. In one form it develops in middle life. Such persons become blind. In a study made of 304 families in which this defect occurred, it was found that over half of the thousand children inherited the defect, although the defective parent mated with a normal person. Again, studies of inheritance of certain types of deafness and deaf-mutism showed these to be inherited by children. In all

of these cases the defects act as handicaps to a normal life. Not only do they involve suffering for the possessors of these characters but a tax upon society. One of the great discoveries of medical science is that of Prophylaxis which means the *prevention* of disease. Nevertheless, all dominant defects could be largely eliminated from human society by preventing such persons from having children.

Feeble-minded persons, as a rule, are supported in public institutions. The care taken of them is a by-product of modern euthenical policy. The children of two feeble-minded parents are also feeble-minded. Goddard, in charge of the State Home for the Feeble-minded at Vineland, New Jersey, collected data with regard to the offspring of 122 marriages of the congenitally feeble-minded. They had 482 children, of whom 476 were feeble-minded. He collected data with regard to the offspring of parents, one of whom was normal and the other feeble-minded. From 122 pairs of such parents came 371 children, 193 of whom were feeble-minded and 178 normal. Goddard's studies indicate that feeble-mindedness behaves like a Mendelian recessive. A feeble-minded little girl, an inmate of this splendid institution, had a feeble-minded brother. Both parents were feeble-minded. Goddard looked up this family history. Among the relatives of the same generation as the child he found 16 feeble-minded out of a total of 25, i.e., 64 per cent were feeble-minded; of the parental generation 21 feeble-minded out of a total of 25 persons, or 84 per cent; and of the grandparent generation 6 feeble-minded out of a total of 8, or 75 per cent.

A striking and now classical case of this is the descendants of the so-called Martin Kallikak, a family history unearthed by Goddard. Kallikak had children by a feeble-minded girl during the American Revolution. There were 480 descendants traced from this mating and all below normal intelligence. On the whole, they have been a burden on society. At the close of the War, this soldier married a normal girl, and 406 descendants of this mating are known. All these were normal in intelligence and contributors to the common good. One of the causes of feeble-mindedness

is syphilis. More feeble-minded children appear in the children of alcoholics than among children of non-alcoholic parents. Prevention of children in the feeble-minded is clearly indicated by the above studies. Abnormality will continue to appear as long as there are parents who are alcoholic and syphilitic. In the study of physiology presented here, it was pointed out that a cretin is an idiotic or feeble-minded, undeveloped individual, a condition brought about by the failure of the thyroid gland to develop. Some years ago in a certain valley in Italy, 60 per cent of the population were cretins. They were allowed to intermarry and the offspring were cretins. Finally a law was passed forbidding marriage of cretin with cretin. To-day but few cases remain. This is an example of the effects of a eugenic program. Studies of the pedigrees of inmates of insane asylums who are usually committed after middle life and so after some years of married life indicate the inheritance of many forms of nervous instability or abnormality in their offspring.

One of the best illustrations of the perpetuation of the unfit is shown by the pedigree of the Jukes family of New York State. In five generations this family numbered about 1200 people and was distinctively an American family. Its history is known back to 1720. Kellicott says: "Of these 1200 idle, ignorant, lewd, vicious, pauper, diseased, imbecile, insane and criminal specimens of humanity, about 300 died in infancy. Of the remaining, 310 were professional paupers in almshouses, a total of 2300 years [at whose expense?]; 440 were physically wrecked by their own diseased wickedness; more than half of the women were prostitutes; 130 were convicted criminals; 60 were habitual thieves; 7 were murderers. They have cost the state over a million and a quarter dollars, and the cost is still going on."

On the other hand, the history of the famous Edwards family of New England is just as bright as the Jukes' case is dark. Jonathan Edwards was a clergyman in the early days of New England. He was a man of unusual ability. In 1900, 1394 of his descendants had been identified. Of

these 299 were college graduates; 13 were college presidents; 65 were college professors; 60 were physicians; 100 or more clergymen; 75 were officers in the army or navy; 60 were prominent authors and writers; 100 were lawyers; 30 were judges; 3 were U. S. Senators, one was a Vice-President of the United States, many were eminent in law, theology, medicine, business, education and public service. It is not known that any were criminals. The general contribution to social progress made by this family has been decidedly positive and constructive. The general contribution of such as the Jukes family has been decidedly negative and destructive.

Darwin summed up the general attitude of society in these words, " Except in the case of man himself—hardly anyone is so ignorant as to allow his worst animals to breed."

Such agencies as the Galton Laboratory for Eugenics in England and the Eugenics Record Office at Cold Spring Harbor, N. Y., and the active work of the Eugenics Associations, may lead to a correction of these ills. A wisely informed public can throw the weight of public opinion in the right direction. Not one iota of thoughtfulness and kindly treatment of the unfortunate should be surrendered from the present euthenical policy, for the net gain to society is greater than all the loss. But practical eugenics can eliminate most of the cost of poor Euthenics.

An attempt at better immigration laws has been begun. Some states now have eugenic marriage laws. Defectives should be prevented from polluting the national germ plasm with descendants like themselves. Every sensible inducement should induce the genetically fit to produce at least two children. War is a most dysgenic phenomenon. In war the eugenically fit are destroyed and nations thus lose far more than they gain.

Selection in Birth.—Unrestricted birth rate together with poor euthenics and eugenics leads to overcrowding and misery. The increase in food supply does not always keep pace with increase in population. There are many examples of organisms overpopulating a district and the

result is a terrible death rate in the organism which is reproducing so riotously. If every nation placed a limit upon the population which its resources could maintain, one of the fruitful causes of war would be removed. How this can best be done is unsolved. Education in the real purpose of sexual reproduction will be included in whatever method is best.

Human Activities and Biology.—It is surprising to note that the great mass of the world's population is engaged primarily in making it possible for human beings to exist, to function biologically. Millions of persons spend their lives as accessory agents to the metabolism of human organisms. Compare the methods used by animals or primitive peoples and civilized society in securing food, water, shelter and removal of body wastes.

1. *Air.*—Oxygen is a primary requisite for bodily oxidations. It is ample and free to most persons, but ventilation engineers are needed in the construction of great buildings to be occupied by human beings. Air pollution receives proper newspaper publicity whenever necessary.

2. *Water.*—Water is the vehicle whereby physiological processes are made possible. It is a very serious problem in California where long periods of dry weather prevail. In all large cities, gigantic engineering projects must be carried out to provide ample supplies of good water.

3. *Food Supply.*—Food is required as a source of body energy and to replace worn-out protoplasm, and for growth. Great numbers of plant and animal growers spend their lives in providing food for their fellowmen. Fresh food spoils quickly and so thousands of other persons are engaged in salting, drying and canning food. Great railroad systems and steamship lines with brigades of helpers are concerned in transporting food supplies to the human organism. Freight handlers, truckmen, commission men, accountants, merchants, grocers and meat men are also agents in this matter. Millions of dollars in buildings, equipment and lands are involved.

4. *Temperature Regulation.*—The human animal is constant temperatured. By nature he is adapted to a trop-

ical climate. But due to his intelligence, he has devised aids to his body and consequently is able to exist in relatively cold climates. The cold has undoubtedly been a stimulus to greater achievements. Think of the corps of persons engaged in various divisions of this matter of helping the body to live and work and play at lower temperatures than those to which it can readily adjust itself. There is the wool and cotton grower, the cloth maker and the tailor, together with transportation and merchandising of these goods. But clothing alone is insufficient. To the above list must be added the coal miner, the furnace maker, the heat engineer and furnace tender.

5. *Shelter.*—While the animal and primitive man exist in crude shelters of nature, civilized man lives more abundantly when his functions can actively continue independent of the weather. The forester, the lumberman, the brickmaker; the cement maker, the quarryman, the mason, the carpenter, the steelmaker, the toolmaker, the transport worker and merchant are again involved.

6. *Excretion.*—To the animal or primitive man, disposal of body wastes requires little attention, although neglect of proper disposal makes for extinction as indicated by the hookworm infection. In great congested districts it becomes a serious problem. Disposal of garbage and sewage is a municipal affair that requires the expenditure of great sums.

These are examples of the kinds of work that a great part of the world's population is engaged in and every one of these activities is concerned with making it possible for human organisms to function. We too often overlook these facts. A small proportion of the people of the earth take these things for granted. The type of person referred to is not only not interested in any necessary enterprises, but is after all no better than a parasite on others, and should be compared with such organisms as the tapeworm or disease germ.

The plant and animal worlds offer many illustrations of social organizations of one type or another. Human

society is the most complex of all and since it consists of living organisms, a satisfactory study of it involves biology. Man has found great advantages in social organization, which is an outgrowth of the more primitive solitary individual existence. In taking up group living, the individual always has to give up a certain freedom of action which belongs to the solitary life. In spite of this newer social interrelationship, the old first law of self-preservation remains and is at times in conflict with later social responsibilities. Man has learned that on the whole he is much better off in the new way of living. A great complicated and more or less integrated sort of organism has blundered its way onward through the ages. To-day thieving and murder are examples of the continual outcropping of the old order of things. The criminal is one born without asking to be born into an order of things for which he is not fitted. So intricate has this social organism become, that it is quite impossible to conceive of civilized men apart from such a mode of living. Biological study indicates that the state is but a group of living organisms associated for mutual benefit.

Are there evidences of human evolution? Is man static or is he deteriorating? There are some who claim to see in present-day life plenty of evidence of retrogression. Is the human race moving toward any goal? Is the brain of man capable of continuing to maintain order in a world of constantly increasing complicated contacts between alien peoples? Man certainly differs from the lower animals in that he has a greater mental equipment for determining his goal and thus controlling his evolution. These questions involve a study of mind, personality and spirit and transcend what is ordinarily referred to as Biological Science.

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APPENDIX A[1]

CLASSIFICATION OF PLANTS

Phylum I.—Thallophyta.

Sub-phylum I—Algae.

Class 1—Cyanophyceae (Blue-green Algae, 1200 species), Fission Algae.

Examples—Gleocapsa, Nostoc, Oscillatoria, Anabaena, Rivularia, Trichodesmium (Red Sea).

Class 2—Chlorophyceae (Green Algae, 9000 species), Unicellular-green Algae, Desmids, Diatoms, Confervas, Pond Scums, Sea Lettuce, Tubular Algae, Stoneworts.

Examples—Pleurococcus, Sphaerella, Chlamydomonas, Gonium, Ulothrix, Ulva, Oedogonium, Cladophora, Spirogyra, Cosmarium, Navicula, Vaucheria, Chara.

Class 3—Phaeophyceae (Brown Algae, 1000 species), Kelps and Rockweeds.

Examples—Ascophyllum, Fucus, Ectocarpus, Laminaria, Macrocystis, Postelsia, Sargassum.

Class 4—Rhodophyceae (Red Algae, 3000 species).

Examples—Chondrus, Nemalion, Batrachospermum, Callithamnion, Dasya, Polysiphonia, Rhabdonia.

Sub-phylum II—Fungi.

Class 1—Schizomycetes (Bacteria, 1400 species).

Examples—Bacillus vulgaris, Bacillus typhi, Vibrio, Spirillum.

Class 2—Myxomycetes (Slime Molds, 400 species), Slime Fungi, Fungus-animals.

Examples—Aethalium, Fuligo.

[1] Several groups of organisms were omitted from the discussion in the text. The same is true of this Classification of Plants and Animals. The system of numbering in the Classification agrees with that used in the text.

Class 3—Phycomycetes (Alga-like Fungi, 330 species), Blights, Mildews, True Molds.
Examples—Rhizopus, Mucor, Saprolegnia, Albugo, Phytophthera.
Class 4—Ascomycetes (Sac Fungi, 20,000 species), Black Fungi, Mildews, Yeasts, Blue and Green Molds, Lichens.
Examples—Penicillium, Aspergillus, Peziza, Morchella, Claviceps, Physcia, Cladonia, Usnea, Saccharomyces.
Class 5—Basidiomycetes (Basidia Fungi, 20,000 species), Smuts, Rusts, Toadstools, Puff Balls, Mushrooms.
Examples—Ustilago, Puccinia, Clavaria, Boletus, Hydnum, Agaricus, Coprinus, Amanita, Geaster.

Phylum II.—Bryophyta, 16,000 species.

Class 1—Hepaticae (Liverworts).
Examples—Ricciocarpus, Marchantia, Porella, Anthoceros.
Class 2—Musci (True Mosses), True Mosses and Peat Mosses.
Examples—Funaria, Bryum, Polytrichum, Sphagnum.

Phylum III.—Pteridophyta, 4500 species.

Class 1—Filicineae (Ferns).
Examples—Aspidium, Pteris, Dicksonia, Osmunda, Onoclea, Nephrolepis, Gleichenia, Polypodium, Marsilia, Ophioglossum, Botrychium.
Class 2—Lycopodineae (Club Mosses).
Examples—Lycopodium, Selaginella, Isoetes, Bepidodendrum.
Class 3—Equisetineae (Horsetails).
Examples—Equisetum, Calamites.

Phylum IV.—Spermatophyta.

Class 1—Gymnospermae (Gymnosperms), 500 species.
Order 1—Cycadales—(Cycads).
Examples—Cycas, Zamia.
Order 2—Coniferales (Conifers).
Examples—Pine, Fir, Spruce, Hemlock, Yew, Cedar, Cypress, Redwood, Larch, Juniper, Arbor Vitae.
Class 2—Angiospermae.

Sub-class 1—Dicotyledoneae, 100,000 species.
Order 1—Salicales—Willows.
Order 2—Juglandales—Walnuts, Hickories.
Order 3—Urticales—Elm, Fig.
Order 4—Rosales—Roses, Apple, Pear, Plum, Peach, Currant, Strawberry, Cherry, Beans, Peas.
Order 5—Sapindales—Maples.
Order 6—Opuntales—Cactus.
Order 7—Tubiflorae—Sweet Potato, Mint, Tobacco, Tomato, Potato.
Order 8—Campanulales—Squash, Pumpkin, Cucumber, Melon.
Sub-class 2—Monocotyledoneae (Monocotyledons), 30,000 species.
Order 1—Naidales—Water Plants.
Order 2—Graminales—Grasses, Corn, Wheat.
Order 3—Palmales—Palms.
Order 4—Liliales—Lily, Asparagus, Iris, Tulip, Narcissus, Hyacinth.
Order 5—Scitaminales—Banana, Canna.
Order 6—Orchidales—Orchids.

CLASSIFICATION OF ANIMALS

Phylum I.—Protozoa. (One-celled animals.) About 10,000 species.
Class 1—Rhizopoda. (Locomotion by means of pseudopodia.)
Examples—Amoeba, Entamoeba, Difflugia, Arcella, Globigerina, Actinophrys, Thallasicola.
Class 2—Mastigophora. (Locomotion by means of flagella.)
Examples—Spirochaeta, Treponema, Trypanosoma, Euglena, Synura, Pandorina, Volvox, Noctiluca.
Class 3—Infusoria (Locomotion by means of cilia.)
Examples—Paramoecium, Stentor, Stylonichia, Vorticella, Oxytricha, Euplotes, Didinium.
Class 4—Sporozoa. (Parasitic.)
Examples—Porospora, Gregarina, Monocystis, Plasmodium.

Metazoa. (Many-celled animals; see the following Phyla.)

Phylum II.—Porifera. (Pore-bearing animals—The Sponges.) About 2500 species.

Class 1—Calcarea. (Simple sponges.)
Examples—Grantia, Leucosolenia.

Class 2—Hexactinellida. (Glass sponges.)
Examples—Euplectella, Hyalonema.

Class 3—Demospongiae. (Large, compound sponges, skeleton with spongin.)
Examples—Euspongia, Chalina, Cliona, Tethya.

Phylum III.—Coelenterata. (Hollow-intestine animals.) About 4300 species.

Class 1—Hydrozoa. (Asexual hydroids with sexual medusoid stage.)
Examples—Hydra, Pennaria, Campanularia, Obelia, Gonionemus, Physalia.

Class 2—Scyphomedusae. (Larger Jellyfish, medusoid stage conspicuous.)
Examples—Aurelia, Cyanea.

Class 3—Actinozoa. (Corals and Sea-anemones.)
Examples—Corallium, Astrangia, Meandrina, Fungia, Metridium, Sagartia, Pennatula.

Class 4—Ctenophora. (Comb - bearing animals — comb jellies.)
Examples—Mnemiopsis, Beroe.

Phylum IV.—Platyhelminthes. (Broad intestinal worms—flatworms.) About 4600 species.

Class 1—Turbellaria. (Small free-living flatworms.)
Examples—Planaria, Bdelloura.

Class 2—Trematoda. (Flukes—parasitic.)
Examples—Distomum.

Class 3—Cestoda. (Tape worms.)
Examples—Taenia, Crossobothrium.

Class 4—Nemertea. (Long, contractile, free-living flatworms.)
Example—Cerebratulus.

Phylum V.—Nemathelminthes. (Thread worms.) About 1500 species. (Cobb estimates many thousand species.)

Class 1—Nematoda. (Round worms.)
Examples—Filaria, Trichinella, Ascaris, Necator, Syngamus.

Class 2—Gordiacea. (Hair worms.)
Example—Gordius.
Class 3—Acanthocephala. (Spiny-headed worms.)
Example—Echinorhyncus.
Class 4—Chaetognatha. (Bristle-headed worms.)
Example—Sagitta, the arrow worm.

Phylum VI.—Annelida or Annulata. (Segmented worms.) About 4500 species.
Class 1—Archiannelida. (Primitive annelids.)
Example—Polygordius.
Class 2—Chaetopoda. (Bristle-footed annelids.)
Order 1—Polychaeta. (Many setae.)
Examples—Aphrodite, Syllis, Nereis, Chaetopterus, Cirratulus, Amphitrite, Arenicola, Hydroides.
Order 2—Oligochaeta. (Few setae.)
Examples—Lumbricus, Allolobophora, Tubifex.
Class 3—Hirudinea. (Leeches.)
Example—Hirudo.

Phylum VII.—Echinodermata. (Spiny-skinned animals.) About 4000 species.
Class 1—Crinoidea. (Feather stars, sea lilies.)
Examples—Pentacrinus, Antedon.
Class 2—Asteroidea. (Star fishes.)
Examples—Asterias, Solaster, Asterina, Ctenodiscus.
Class 3—Ophiuroidea. (Brittle stars, snake stars.)
Examples—Ophiopholis, Ophioderma, Gorgonocephalus.
Class 4—Echinoidea. (Sea-urchins, cake urchins, sand dollars.)
Examples—Arbacia, Strongylocentrotus, Echinarachnius, Clypeaster.
Class 5—Holothuroidea. (Sea cucumbers.)
Examples—Cucumaria, Thyone, Leptosynapta.

Phylum VIII.—Mollusca. (Soft animals.) About 60,000 species.
Class 1—Gasteropoda. (Stomach foot.) Snails, whelks, slugs.
Examples—Helix, Limax, Natica, Busycon, Triton, Urosalpinx.
Class 2—Pelecypoda. (Hatchet foot.) Oysters, clams, mussels, scallops.
Examples—Ostrea, Mya, Venus, Mactra, Tridacna, Unio, Lampsilis, Ensis, Pholas, Pecten, Anodonta, Teredo.

Class 3—Cephalopoda. (Head-footed, i.e., head with tentacles.) Squid, cuttle fish, devil fish or octopus.
Examples—Nautilus, Sepia, Loligo, Octopus.

Phylum IX.—Arthropoda. (Jointed foot.) About 430,000 species.

Class 1—Crustacea. (Skin-crust.)
Examples—Daphnia (Water flea), Lepas (Gooseneck barnacle), Balanus (Rock barnacle), Oniscus (Sow bug), Gammarus (Fresh-water shrimp), Homarus (lobster) Cambarus (Crayfish), Callinectes (Blue crab), Penaeus (Shrimp), Libinia (Spider crab).
Class 2—Onycophora. (Claw bearing.)
Example—Peripatus.
Class 3—Myriopoda. (Ten thousand feet.) Centipedes, millipedes.
Examples—Lithobius, Julus, Scutigera.
Class 4—Insecta. (Cut into.)
Order 1—Coleoptera.
Example—Beetles, Weevils, June Bugs.
Order 2—Hymenoptera.
Examples—Ants, Bees, Wasps.
Order 3—Siphonaptera.
Examples—Fleas.
Order 4—Diptera.
Examples—Flies and Mosquitos.
Order 5—Aptera.
Example—Fish Moths.
Order 6—Ephemerida.
Example—May Fly.
Order 7—Odonota.
Examples—Dragon Fly, Darning Needle.
Order 8—Isoptera.
Examples—Termites or White Ants.
Order 9—Orthoptera.
Examples—Cockroaches, Grasshoppers, Crickets.
Order 10—Hemiptera.
Examples—Bugs, Lice, Locusts, Aphids, Scale Insects.
Order 11—Neuroptera.
Example—Ant Lions.
Order 12—Lepidoptera.
Examples—Butterflies and Moths.

Class 5—Arachnida. (Spider.)
Examples—Limulus (King Crab), Scorpion, Tarantula, Spiders, Ticks and Mites.

Phylum X.—Chordata. (Notochord.) About 30,000 species.
Sub-phylum I. Prevertebrates.
Class 1—Hemichorda. (Enteropneusta.)
Example—Balanoglossus.
Class 2—Urochorda. (Tunicata.) Sea-squirts.
Examples—Molgula, Cynthia, Ciona, Salpa.
Class 3—Cephalochorda.
Example—Amphioxus, the lancelet.
Sub-phylum II. Vertebrata. (Craniata.)
Class 1—Cyclostomata. (Round mouth.) (Lampreys and Hag Fish.)
Examples—Petromyzon, Myxine, Bdellostoma.
Class 2—Elasmobranchii.
Examples—Sharks, Skates, Sting-rays, Torpedo, Dog-fish, Saw fish.
Class 3—Teleostomi. Cod, Mackerel, Herring, Shad, Haddock, Swordfish, Tarpon, Trout, Salmon, Pickerel, Suckers, Eels, Seahorse, Goosefish, Gars, Bowfin, Sturgeon, Flounder, Whitefish, Tilefish.
Class 4—Amphibia.
Order 1—Apoda.
Example—Ichthyophis.
Order 2—Caudata. (Urodela.)
Examples—Mud Puppy, Hellbender, Siren, Congo, Eel, Giant Salamander, Salamanders and Newts.
Order 3—Salientia. (Anura.)
Examples—Frogs, Toads, Tree Frogs.
Class 5—Reptilia.
Order 1—Lacertilia—Lizards.
Order 2—Ophidia—Snakes (Serpents.)
Order 3—Chelonia—Turtles and Tortoises.
Order 4—Crocodilia, Alligators, Crocodiles and Gavials.
Class 6—Aves.
Sub-class 1—Archeornithes.
Example—Archeopteryx. (Extinct.)
Sub-class 2—Neornithes.
Division 1—Ratitae.
Example—Ostrich.

Division 2—Carinatae—Emu, Cassowary, Kiwi, Penguin, Albatross, Heron, Flamingo, Ducks, Geese, Terns, Gulls, Fowls, Pigeons, Parrots, Owls, Wrens, Sparrows, Crows.

Class 7—Mammalia.

Sub-class 1—Prototheria or Monotremata.

Example—Spiny Anteater, Duckbill.

Sub-class 2—Metatheria or Marsupialia.

Example—Kangaroo, Opossum, Wallaby.

Sub-class 3—Eutheria or Placentalia.

Order 1—Insectivora.

Moles, Shrews, Hedgehogs.

Order 2—Chiroptera.

Bats and Flying Foxes.

Order 3—Sirenia.

Manatee and Dugong.

Order 4—Cetacea.

Whales, Porpoises, Dolphins.

Order 5—Edentata.

Sloth, Anteater, Armadillo.

Order 6—Rodentia.

Mice, Rats, Rabbits, Squirrels, Beavers, Porcupines, Guinea Pigs.

Order 7—Ungulata.

Sub-order 1—Artiodactyla—Pigs, Camels, Giraffes, Cattle, Deer, Hippopotamus, Bison, Moose.

Sub-order 2—Perissodactyla—H o r s e s , Zebras, Tapirs, Rhinoceroses.

Sub-order 3—Proboscidea—Elephants.

Order 8—Carnivora.

Sub-order 1—Fissipedia.

Examples—Dogs, Cats, Foxes, Lion, Tiger, Leopard, Lynx, Skunk, Wolves, Raccoon, Bears, Weasels, Otter.

Sub-order 2—Pinnipedia—S e a l s , W a l r u s e s , Sea Lions.

Order 9—Primates.

Family 1—Lemuroidea.

Example—Lemurs.

Family 2—Hapalidae.

Example—Marmosets.

Family 3—Cebidae.
Examples—Howling Monkeys, Spider Monkeys.
Family 4—Cercopithecidae.
Examples—Macaques and Baboons.
Family 5—Simiidae.
Examples—Gibbon, Orang-utan, Chimpanzee, Gorilla.
Family 6—Hominidae.
Example—Man.

APPENDIX B

DISTRIBUTION OF ORGANISMS IN TIME

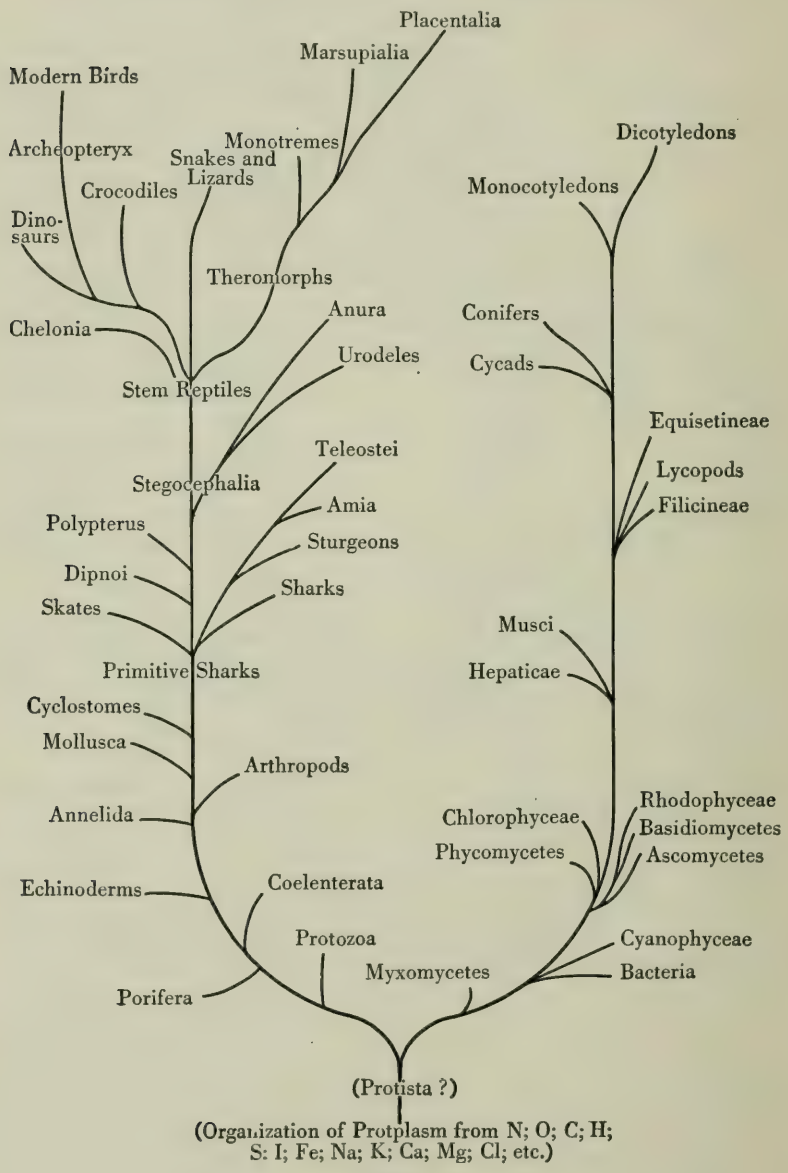
Era.	Periods.	Characteristic Organisms.
I. Formative	.....	Earth formed from masses of gas thrown off from the sun, surface molten; surface cooling; spheroidal shape; surface rigid; water, atmosphere, oceans and land formed.
II. Archeozoic	.....	Living matter organized.
III. Proterozoic	.....	Two ice ages. Primitive Invertebrates.
IV. Paleozoic (Ancient Life)	Cambrian	Trilobites, Cephalopods, Marine Plants.
a. (Age of Invertebrates)	Ordovician	Shelled Invertebrates; Fishes;
b. (Age of Fishes)	Silurian, Devonian Mississipian	Land Plants; Lung Fish; Marine Fishes; Corals at Maximum, Crinoids at Maximum, Great Marine Sharks. Amphibians (Stegocephalian).
c. (Age of Amphibians and Ancient Plants)	Pennsylvanian Permian (Icy Climate)	Giant Pteridophytes, Primitive Insects; Primitive Reptiles. Land Vertebrates (Reptiles).

DISTRIBUTION OF ORGANISMS IN TIME—*Continued.*

Era.	Periods.	Characteristic Organisms.
V. Mezozoic (Mediaeval Life)	Triassic	Rise of Dinosaurs and Cynodonts (mammals) Ichthyosaurs.
	Jurassic	Pterodactyls and Birds (Archeopteryx) Lepidopteran and Hymenopteran Insects.
	Comanchian	Flowering Plants and Insects.
d. (Age of Reptiles)	Cretaceous	Primitive Mammals. Flowering Plants and Insects. Hesperornis.
		Higher Mammals; Social Insects.
		Decline of Great Reptiles (Dinosaurs).
VI. Cenozoic (Modern Life)	Eocene	Modern Birds; Eohippus. Protylopus.
e. (Age of Mammals and Flowering Plants).	Oligocene-Miocene	Primates; Mesohippus. Higher Apes; Merychippus. Mammals at Maximum.
	Pliocene	Ape-man; Mastodon, Camels.
	Pleistocene or Glacial.	Large Mammals extinct; Equus; Human Civilization Dawns.
VII. Psychozoic *f.* (Age of Man)		Evolution of Human Races and Civilization.

APPENDIX C

GENEALOGICAL TREE OF ORGANISMS



(Organization of Protplasm from N; O; C; H; S: I; Fe; Na; K; Ca; Mg; Cl; etc.)

APPENDIX D

Biographical Catalogue of Some Master Biologists[1]

Hippocrates (460–370 B.C.). Greek; "Father of Medicine." Applied the scientific method in treating disease.

Aristotle (384–322 B.C.). Greek philosopher, investigator and teacher. Pupil of Plato. Teacher of Alexander the Great. Established the science of Natural History. Writings extensive, "History of Animals," etc. His writings looked upon as authoritative for centuries.

Galen (A.D. 131–201) Greek, practiced medicine and taught anatomy at Rome. His "Anatomy" based on information derived from dissection of lower animals and so contained errors. Nevertheless it was taught for centuries.

Vesalius, Andreas (1515–1564). Belgian; studied at Louvain, Leyden, Paris. Professor of Surgery at Padua. Wrote first good text book of Human Anatomy in 1543.

Fabricius, Hieronymus (1537–1619). Pupil of Fallopius at Padua. Later professor of Anatomy at Padua and taught William Harvey.

Harvey, William (1578–1657). Graduate of Cambridge, M.D., Padua. Physician to King Charles I. Lecturer in Anatomy. Discoverer of the Circulation of the Blood, 1628. Studied Embryology also. "Father of Modern Medicine."

Redi, Francesco (1626–1698). Italian. His experiments in disproof of spontaneous generation.

Malpighi, Marcello (1628–1694). Professor at Bologna. Indefatigable investigator. Anatomy of Silkworm; Embryological studies. Anatomy of Plants.

Swammerdam, Jan (1637–1680). Dutch. Ardent investigator of minute forms. Devised method of injecting blood vessels, master of minute anatomy of insects.

[1] The chronological order is departed from at times to group related workers. This list is by no means complete.

Hooke, Robert (1635–1703). English. Brilliant and versatile in physics, mathematics and natural history. First used the word "cell."

Grew, Nehemiah (1628–1711). English botanist. His Anatomy of Vegetables, the beginning of plant histology.

Ray, John (1628–1705). Worked in botany and zoology. The "Ray Society" of London named in honor of John Ray.

Leeuwenhoek, Antony van (1632–1723). Self-educated. Holland. Microscopic biology. Fellow Royal Society, London.

Haller, Albrecht von (1708–1777). Professor Botany, Anatomy and Medicine at Göttingen. Wrote "Elements of Physiology," 1757–65.

Linnæus, Carolus (1707–1778). Professor of Botany at Upsala. His "Systema Naturae" (10th ed. 1758), a comprehensive survey, a model taxonomy in which he introduced the binomial system of nomenclature. Opposed evolution.

Buffon, George, *Comte de* (1707–1778). French naturalist, Superintendent of Jardin du Roi. Author of "Histoire Naturelle." Probably believed in evolution.

Camper, Peter (1772–1789). Dutch. Anatomist. Made a number of discoveries in anatomy.

Hunter, John (1728–1793). Scotch. Surgeon. Established great anatomical museum in London.

Wolff, Caspar (1733–1794). Breslau and St. Petersburg. Author of "Theoria generationis," 1759, and "De formatione intestinorum," 1768–1769. Opposed preformation with his epigenesis theory of development.

Spallanzani, Lazarro (1729–1799). Professor at Modena and Pavia. His experiments in disproof of theory of spontaneous generation.

Darwin, Erasmus (1731–1802). Physician in England. Fellow Royal Society. Author of Zoonomia. Argued for evolution.

Treviranus, Gottfried (1776–1837). Germany. One of the first to use word Biology, "Biologie, oder Philosophie der lebenden Natur," 1802.

Lamarck, Jean Baptiste de (1744–1829). French. Jardin des Plantes. Botany, zoology, evolution. "Philosophie zoologique," 1809.

Cuvier, Georges (1769–1832). Baron of France; protégé of Napoleon Bonaparte. Jardin des Plantes. Founder of comparative anatomy and palaeontology. Opposed idea of evolution.

GOETHE, JOHANN WOLFGANG VON (1749–1832). Poet, philosopher and naturalist. "Versuch die Metamorphose der Pflanzen zu erklären," 1790. Evolutionist.

SAINT-HILAIRE, GEOFFROY (1772–1844). Jardin des Plantes. "Philosophie Anatomique," 1818. Debated with Cuvier on evolution.

BAER, KARL ERNST VON (1792–1876). Professor at Königsberg and St. Petersburg. Founded Comparative Embryology.

MÜLLER, JOHANNES (1801–1858). Professor at Berlin. Comparative Physiology. A master intellect. "Handbuch der Physiologie des Menschen."

SCHLEIDEN, MATTHIAS (1804–1881). Professor of Botany at Jena. Founder of Cell Theory with Schwann. "Ueber Phytogenesis," 1838.

SCHWANN, THEODOR (1810–1882). Professor of Anatomy at Liège. (See Schleiden.) "Mikroskopische Untersuchungen," 1839.

LIEBIG, JUSTUS VON (1803–1873). Chemist. Professor at Munich. Organic Chemistry in Relation to Agriculture and Physiology, 1840.

LYELL, CHARLES (1797–1875). Geologist. "Principles of Geology," 1830–1833. This aided Darwin in developing his arguments for the theory of evolution.

SCHULTZE, MAX (1825–1874). Professor at Halle and Bonn. "Father of Biology," showing that protoplasm is similar in plants and animals.

DARWIN, CHARLES (1809–1882). Graduated from Cambridge University. Voyage of the *Beagle*, 1831–1836. Origin of Species, 1859. Descent of Man, 1871. Darwin established the Theory of Evolution.

HOOKER, JOSEPH (1817–1911). Contemporary of Darwin. Botanist. His "Flora of British India," appeared in 1872–1879.

MENDEL, GREGOR (1822–1884). Abbot of monastery at Brünn, Austria. Wrote "Versuch über Pflanzen-Hybriden," 1865. Founder of modern science of Genetics.

AGASSIZ, LOUIS (1807–1873). Professor of Geology and Zoology at Harvard. Founded Museum of Comparative Zoology at Harvard in 1859. Founded what is known now as the "Marine Biological Laboratory." A great teacher. Opposed to the theory of evolution.

BERNARD, CLAUDE (1813–1878). Experimental physiologist in

Paris. Wrote a book on "Phenomena Common to the Life of Animals and Plants." Made a number of important discoveries in physiology.

Milne-Edwards, Henri (1800–1885). Professor at the Sorbonne. "Physiology and Comparative Anatomy," 1857–1880.

Dubois-Reymond, Emil (1818–1896). Succeeded Müller as Professor of Physiology at Berlin. Investigated animal electricity.

Gray, Asa (1810–1888). Professor of Botany at Harvard. His Manual of Botany is the standard Plant Taxonomy.

Leidy, Joseph (1823–1891). Professor of Anatomy at Pennsylvania. "Fresh Water Rhizopods of North America," 1879. "Mammalian Remains in Nebraska," 1853.

Loeb, Jacques (1859–1924). Physiologist. Professor at Bryn Mawr, Chicago, California, and Member of Rockefeller Institute for Medical Research in New York. Career devoted to explaining life phenomena in terms of physics and chemistry. Prolific and profoundly stimulating investigator.

Owen, Richard (1804–1892). Professor of Anatomy at London, British Museum. Anatomy and Physiology of the Vertebrates. Fossil Birds. Opposed idea of evolution.

Pasteur, Louis (1822–1895). Professor of Chemistry at Strasburg, Lille, Sorbonne. Director, Pasteur Institute, Paris. Fermentation and Bacteriology.

Ludwig, Carl (1816–1895). Professor at Leipsig. Developed graphic method of recording physiological processes.

Huxley, Thomas Henry (1825–1895). Investigator in anatomy and palaeontology. Teacher, lecturer and great exponent of the theory of evolution.

Cope, Edward Drinker (1840–1897). Professor at Pennsylvania. Palaeontologist with U. S. Geological Survey. "Origin of the Fittest," 1886.

Marsh, O. C. (1831–1899). Professor of Palaeontology at Yale. Collections of fossil horses, etc.

Zittell, Karl von (1839–1904). Professor at Munich. Author of standard textbook on Palaeontology.

Virchow, Rudolph (1821–1903). Professor at Berlin. Author of "Cellular Pathology," 1858.

Gegenbaur, Carl (1826–1903). Professor at Heidelberg. Comparative anatomy.

Koelliker, Albrecht von (1817–1905). Professor at Würzberg, Embryologist and Histologist, "Handbuch der Gewebelehre," 1852–1893.

Koch, Robert (1843–1910). Professor at Berlin. Relation of Bacteria to Disease.

Galton, Francis (1832–1911). Heredity and Eugenics. Cousin of Charles Darwin.

Wallace, Alfred Russel (1822–1913). Naturalist. "Geographical Distribution of Animals," 1876. Contemporary of Darwin and arrived at a theory of evolution by Natural Selection at about the time Darwin was ready to publish "The Origin of Species."

Weismann, August (1834–1914). Professor of Zoology at Freiburg. Wrote the "Germ Plasm Theory," 1893. The development of the germ plasm idea focused attention on the chromosomes and laid the basis for work in genetics. Weismann strenuously opposed the inheritance of acquired characteristics.

Fischer, Emil (1852–1919). Great chemist. German. Worked on synthesis of carbohydrates, on proteins, etc.

Haeckel, Ernst (1834–1919). Professor of Zoology at Jena. Author of "Generelle Morphologie," 1866. "Die Radiolarien," 1862. "History of Creation," 1911. An ardent evolutionist.

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